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Progressive Refinement of a CSCL-Based Lesson Plan for Improving Student Learning as Knowledge Building in the Period for the Integrated Study

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Abstract. Although constructivism has been prevailed across schools in Japan, what they call constructivism is a "shallow" one (Scardamalia, & Bereiter, 2002). In collaboration with teachers at a laboratory school, we have been conducting design studies on a lesson for knowledge building from the perspective of "deep" constructivism. For embodying such a new lesson, a CSCL technology called Knowledge Forum® has been introduced. Through the progressive refinement of lesson plans, we have been involved in creating pedagogical design principles (Linn, Davis, & Bell (Eds.), 2004) by referring to the metaprinciples on knowledge building (Scardamalia, 2002). In this report, we describe our refinement process of a fifth-grade lesson on genetically modified foods through two years, and discuss how the pedagogical design principles can be transformed into design elements.

Keywords: knowledge building, design principles, design studies, the period for the integrated study

LEARNING AS KNOWLEDGE BUILDING

In the educational reform debate in Japan, people are still in puzzlement with regard to the unsolved dichotomy in decision making: intellectual curiosity vs. basic skill training. In 2003, the Ministry of Education, Science, Sports, and Culture reformed their national guideline by introducing a totally new course called "the period for the integrated study." For deploying such a new part in the existing curriculum, the ministry reduced the time for other subjects by 30 % then cordoned more than 100 class hours a year from the third grade through the ninth grade (i.e., elementary and junior high schools). They are planning to gradually extend this curriculum to the tenth through twelfth grade (i.e., senior high schools).

What is currently happening, on the contrary, is that some schools just go back to the basics by using the period to make students engage in skill acquisition. The schools claim that they need to educate students basic skills rather than having students think of what to learn by themselves. The phenomenon like this manifests that many schools cannot have their visions on the period for the integrated study as time for students to engage in meaningful learning. A reason behind the situation is that schools do not have sufficient resources to establish their own curriculum based on a new epistemological idea on students as life-long learners or knowledge builders.

The goal of our research project funded by the ministry of education, science, sports, and culture in Japan is to establish a curriculum in the period for the integrated study by designing and progressively refining lessons based on knowledge resources by practitioners and learning scientists (e.g., Oshima, Oshima, Inagaki, Nakayama, Yamaguchi, Takenaka, & Murayama, 2003; Oshima, Oshima, Murayama, Inagaki, Takenaka, Nakayama, & Yamaguchi, 2004). The epistemology of learning we have adopted to our design studies is "learning as knowledge building (Scardamalia, & Bereiter, 2002)." In the view of learning as knowledge building, we see students work at the *frontier* of their shared understanding and collaboratively build their knowledge on the top of their current understanding. Scardamalia (2002) describes twelve metaprinciples ("determinants" in her original word) for making the classroom a knowledge building community. A central notion of the metaprinciples is "collective cognitive responsibility." People who are identified to engage in knowledge building should be building knowledge for the purpose of contributing to the advancement of collective understanding in their community. The notion is decomposed into twelve principles as follows:

1. *Real ideas, and authentic problems*. In the classroom as a knowledge building community, learners are concerned with understanding based on their real inquiries. Problems usually used in the classroom are far from students' real concerns with the world they live in. On the other hand, if students are allowed to pursue any

topic with no tools for their learning, the activities do not support learning or knowledge building. Thus, we need to scaffold students to be keen on their inquiries and articulate their inquiries as pursuable problems.

2. *Improvable ideas*. Students' ideas on their learning materials and problems are regarded as improvable objects. Ideas are objectified and shared in some ways as conceptual artifacts (Bereiter, 2002) so that students can engage in discourse around them.

3. *Idea diversity*. The diversity of ideas raised by students is a natural and necessary context of knowledge building in the classroom. In didactic instruction, teachers take cognitive responsibility to manage the diversity, often ignoring it or subordinating it to their predetermined agenda. In the knowledge building classroom, students themselves take on the responsibility for managing their ideas to improve collective understanding.

4. *Rise above*. Through the improvement of ideas or understanding, students create more inclusive syntheses or super-ordinate concepts by summarizing previous ideas.

5. *Epistemic agency*. Students themselves manage how their knowledge could be advanced. They coordinate their personal ideas with others, and also monitor how their collaborative efforts proceed. These tasks require them to exert cognitive strategies for collaborative problem solving.

6. *Community knowledge, collective responsibility*. Students' contribution to improving their collective knowledge in the classroom is the primary purpose of the knowledge building classroom. The shift in their recognition from "learning as the improvement of individual knowledge" to "learning as individual contributions to the collective understanding" is crucial.

7. *Democratizing knowledge*. All individuals contribute to the knowledge advancement in the classroom in various ways. As designers of knowledge building environments, we must be carefully concerned with how students' group works can contribute to their collective knowledge advancement.

8. *Symmetric knowledge advancement*. A goal for knowledge building communities is to have individuals and organizations actively working to advance their knowledge, and have their advances at the same time serve to advance the knowledge of others. Thus there is reciprocity in knowledge work, with the outputs of one group helping another group, and creating a whole that is greater than the sum of the parts.

9. *Pervasive knowledge building*. Students acquire a disposition to contribute to collective knowledge building. It is not something they do at special moments, or in special classes, or during particular curriculum activities. Rather it is integral to how they approach all knowledge problems and it is extensible across contexts, grades and working contexts.

10. *Constructive uses of authoritative sources*. Problems of passive reading and inert knowledge are frequently reported in the literature. Another form of passivity comes from treating text as the ultimate, authoritative source. In the knowledge building classroom, students are encouraged to use resources as conceptual artifacts that are treated as objects of inquiry, and juxtaposed against their personally constructed artifacts. In terms of the van Dijk and Kintsch (1983) model of reading comprehension, knowledge builders actively create both a situation and text model, working actively with both models in ways that lead to more effective learning. Visiting experts in the classroom are not teachers who know everything, but co-researchers. All members, including the teacher, sustain inquiry at the cutting edge of their understanding.

11. *Knowledge building discourse*. Students are engaged in discourse to objectify their ideas, to share with each other, and to improve the knowledge advancement in the classroom. Scientific discourse is a typical form of knowledge building discourse. Conceptual artifacts in scientific discourse are frequently objectified as propositional knowledge. There are strategic discourse patterns for improving the conceptual artifacts (Bereiter, 1994, 2002). Appropriate scaffold supports encourage students to engage in such progressive discourse on their ideas.

12. *Concurrent, embedded and transformative assessment*. For the knowledge advancement, appropriate monitoring is crucial. Students need to look at a total view of their understanding then decide how to proceed in their knowledge building. They create portfolios, comment on each other's work, and engage in a variety of self-monitoring activities. They do not wait for outside experts to evaluate them, but rather evaluate their own progress on an ongoing basis. Accordingly, they are often able to exceed the expectations that others set for them. This collective effort by students to reflect on their collective knowledge is facilitated by the engagement of the teacher as a member of the knowledge building community, not the sole community member responsible for evaluating progress.

In this study, we transformed the twelve metaprinciples into several pedagogical and pragmatic principles (Linn, Davis, & Bell (Eds.), 2004) so that we can concretely design lessons in the classroom. Furthermore, for supporting our lesson plans for knowledge building, a CSCL technology, Knowledge Forum® was implemented in the classroom. In the next section, we describe what pedagogical and pragmatic principles we adopted to our lessons and how we used the CSCL technology to empower student learning as knowledge building.

PEDAGOGICAL DESIGN PRINCIPLES, AND KNOWLEDGE FORUM® AS A TECHNOLOGY TO SUPPORT STUDENTS ENGAGE IN KNOWLEDGE BUILDING

Twelve determinants (Scardamalia, 2002) are general principles across a variety of contexts of knowledge building. Whereas they are useful to identify how much closer our communities are to the knowledge building community, they are somewhat too general to design actual lessons or classrooms at schools. What we had to do at the first step to adopt the knowledge building determinants to our design studies was to transform the determinants into pedagogical or pragmatic principles (Linn et al., 2004). The pedagogical design principles should be descriptions on how and what we need to prepare for supporting student learning as knowledge building. They should be articulate enough and easier to understand for teachers or supporters to take their instructional actions. In our studies on the period for the integrated study, we transformed the determinants into the following four pedagogical design principles.

Student ideas should always be at the center of their practice. Knowledge building is a type of practice in which learners engage in knowledge advancement based on their ideas. In Japanese classrooms, student ideas are sometimes treated as important resources, but cannot exist in the center of their practice all the time. Their ideas are used by teachers to introduce predetermined learning goals, but rarely revisited by students. The idea-centered classroom is, therefore, not familiar to students as well as teachers. For getting student ideas easily elicited and existed at anytime students liked to work on them, we implemented Knowledge Forum® as a medium for students to externalize their ideas in a communal database where they could revisit their previous ideas to collaboratively revise or organize the ideas for their further knowledge advancement. In Knowledge Forum®, students could report their ideas in the form of multimedia notes with scaffolds for their constructive discourse on their own ideas, and revisit their own and others' notes to organize ideas by themselves and their colleagues and build new ideas on their previous ones. Their discourse and manipulation in organizing and building on their ideas are represented as different types of notes in the database and configuration of notes in a hierarchical structure of discussion spaces (called "views").

Student learning should be structured in such a way that every student should have her/his cognitive responsibility. In the knowledge building community or team, every participant should contribute to their collective knowledge advancement. In other words, every participant should have her/his *cognitive* responsibility. In professional organizations, people with different types of expertise are involved in the collective problem solving in this way. In classrooms, however, students are not experts, and do not have recognition on how their own learning is related to others'. For making every student develop their expertise or ideas to contribute to their classroom knowledge, the task structure in which students work on their own ideas and the activity structure by which they collaboratively work on their ideas were designed as follows. Tasks students challenge in the classroom should be *authentic and real problems* elicited from their ideas related to their study topic. Furthermore, the problems should be shared by students to use their expertise to contribute to the advancement of their collective understanding. We, therefore, asked students to generate their *knowledge-based questions* rather than *text-based questions* (Scardamalia, & Bereiter, 1992). In addition, we used collaborative learning by small groups (three or four students per group) as a minimum learning unit in which students with different ideas reciprocally helped one another to solve their challenging problems.

Communication at different group sizes should be encouraged and supported with different media. The classroom knowledge is advanced through student collaboration with different types of discourses happening in the classroom. In Japanese classrooms, student discourse activities are mainly happening at small group or in the classroom as a whole. In our design studies, several cognitive tools such as worksheets for groupwork and Knowledge Forum® were implemented in lesson plans. The implementation of Knowledge Forum® particularly made it possible for students to engage in inter-group discourse during their groupwork. Three different layers of communication, i.e., intragroup, intergroup, and the classroom discourse, were structured for students to gradually transform their *individual* ideas into *more collective* ideas.

Students have opportunities to think of their problems, organize ideas, and reflect on their progress toward what they want to understand. Working on ideas is a really metacognitive aspect of learning. Teachers are usually taking the metacognitive role of student learning. Students are not asked "how would you like to learn on this issue?" or "what do you think we should do for understanding this issue further?" Teachers think that answers to these questions should be included in their material studies and designed as part of their instructions. Teachers know that students bring a variety of ideas related to the study topic, but that it is not possible to expect all beforehand. High quality of teachers redirect a variety of student ideas toward the learning goals predetermined in lesson plans, but rarely take this role over to students themselves. In this study, we designed lesson plans so that students regularly take the metacognitive role of their own learning and a teacher would play another role of supervising students' activities of eliciting problems to be pursued, organizing ideas collaboratively, and reflecting on progress in their learning.

DESIGN STUDIES IN THE PERIOD FOR THE INTEGRATED STUDY: PROGRESSIVE REFINEMENT OF A LESSON PLAN ON GENETICALLY MODIFIED FOODS

A topic we chose for our design studies was "genetically modified foods (GM foods)." GM foods is one of global and authentic issues in our life, and has been scientifically discussed on its advantage and disadvantage (Bell, 2004). In Japan, the Ministry of Health, Labour, and Welfare established their criteria to test GM food safety. Some GM crops have been confirmed their safety and allowed to be put on the market. The reality is, however, that many food product companies do not like to use GM crops as ingredients of their products because their customers are still very anxious about the safety. In our designed lessons, fifth grade students in a classroom at a laboratory school challenged this issue by identifying problems around the issue, conducting research on the problems, and utilizing their knowledge to generate their own solutions to the problems. In the first year, based on the preceding research and practices (e.g., GM foods lessons in WISE project), we designed a lesson plan by implementing design elements (Collins, Joseph, & Bielaczyc, 2004) with the four pedagogical design principles described above. During the practice of lessons, we videotaped how students engaged in learning in the classroom, and how a teacher supported their learning. Analyses on the video records and notes reported on Knowledge Forum® helped us to diagnose our lesson plan and interventions we did during the practice. In the second year, we revised our lesson plan based on our diagnosis of the first year's plan, and conducted again the practice in another fifth grade classroom with the same teacher. Data collected in the second year were compared with those in the first year for evaluating the revision of the lesson plan.

The First Year's Design Study

The Classroom Description

Forty-one fifth grade students (21 females, and 20 males) were engaged in their learning on GM foods in the period for the integrated study. The lesson started in May and continued through July for 23 class hours (A class hour was 45 minutes long.). Students were expected to know about the word but not any scientific mechanism or why they have been being developed. In glossary stores, labels of products usually described that products did not include any GM crops. So, it was difficult for students to actually see food products including GM crops. Parents were concerned with the products with GM crops as ingredients, and might think that the products were not safe enough and caused some allergies to people who were vulnerable to GM crops.

Designing a Lesson on GM Foods

We developed design elements based on the pedagogical principles we adopted, and designed a lesson in the first year as follows.

Student ideas should always be at the center of their practice. The lesson started by asking students of what they thought on GM foods. The teacher created a *concept map* (on the blackboard) based on students' ideas for representing what they knew, and having them share their ideas with each other. Their *classroom concept map* was used further to elicit issues they had to pursue for further learning by themselves. The teacher coordinated their discussion on what issues to be further studied. Students found three issues to be valuable for them to further study: (1) scientific understanding on GM foods, (2) advantages and disadvantages on GM foods, and (3) current situation of GM foods in their real life. Each student chose one of the issues as her/his own theme to be pursued in small groups (The activity structure of small groups are described later.), and their ideas were regularly reported on Knowledge Forum® so that they reflected on their progress and others' at anytime they wanted to do so. The teacher and supporters also created a view on classroom activity reports for students. Pictures on the blackboard and how students were engaged in their learning in each class were reported on the view.

Student learning should be structured in such a way that every student should have her/his cognitive responsibility. Students were not asked to do tasks given by the teacher, but to generate issues for their own study by themselves and take a part of the classroom research. Because they chose their own issue by themselves, motivation to their study was high. In addition, we designed the basic unit of their learning in small groups. A group was composed of three or four students who chose the same issue to study. Students were encouraged to work collaboratively and to report their ideas on Knowledge Forum® as group notes. The teacher supported students to report their collaborative ideas by giving them worksheets where they could write their individual ideas to share them with other group members before reporting on Knowledge Forum®. Ideas reported by groups within/between issues were discussed at different sizes of their classroom community (see details in the next section). In the final stage of their learning, based on their studies on GM foods, students were encouraged to discuss how they should live with this new technology as consumers of food products. In a view called "GM food conference," students expressed their opinions and their reasons or information resources by citing notes on Knowledge Forum® and references at the school library.

Communication at different group sizes should be encouraged and supported with different media. We designed three different layers of communication: intragroup, intergroup, and the classroom discourse. The intragroup communication was mainly based on oral discourse in face-to-face. We implemented worksheets for individual group members to express their ideas before talking to one another within groups. The written discourse by individual group members were used as objects to share and have discourse on for constructing their collaborative ideas.

The collaborative ideas by different groups were further shared to organize as more collective ideas among different groups within the same issues or between different issues. Several scaffolds (a function prepared in Knowledge Forum®) were used for helping students report their ideas as structured arguments. Before starting their groupwork, students discussed how to report their group ideas so that they could share them with one another in a meaningful way. Different structures of arguments were found to be needed in different issues because they applied different types of research methodologies to the three issues. Based on their discussion, the teacher and supporters created different types of scaffolds (a type of tags by which students wrote their ideas in subsection of a note), and students used the scaffolds in writing their arguments in notes. In organizing notes by different groups within the same issues, another function in Knowledge Forum®, "*rise above*," was used. Students could collect similar ideas to drag multiple notes in a "rise above box" and report a summary on their ideas in a superordinate note. The activity of manipulating notes by different groups within the same issue was conducted through the supervision by the teacher. The teacher projected a target view on a screen in front of students working on the issue, and asked students to discuss how to organize their ideas in notes. After organizing their ideas in their target views, students further discussed with students working with different issues on what they found and how their findings were related to one another in the classroom as a whole.

Students have opportunities to think of their problems, organize ideas, and reflect on their progress toward what they want to understand. During their groupwrok, students were encouraged by the teacher to regularly reflect on their progress by reading, revising, and building on notes by themselves and other groups. Some benchmark lessons (Brown, 1989) were designed in our lesson plan. Because the classroom activities were dynamic, we changed our lesson plan by implementing more benchmark lessons at anytime we thought that we needed to do so for students to share important resources or ideas with others.

Evaluation of Student Learning as Knowledge Building

We evaluated our lesson by two different types of analyses on student activities in the classroom. The first analysis was conducted on the quality of problems students had in their learning. Based on their discourse in notes on Knowledge Forum®, we identified four different levels of questions by referring to the categorization by Chan, Lee, & vanAalst (2001). Qualities of students' questions they pursued were compared across different views (or stages of learning). The second analysis was conducted based on our observation of the classroom and the discourse on Knowledge Forum® to figure out what events did happen in relation to the knowledge building determinants (Scardamalia, 2002).

Qualities of Students' Questions Identified in Their Discourse on Knowledge Forum®. Knowledge building is a unique type of cognitive activity, and can be evaluated only by analyzing a process by which learners manipulate their knowledge (Bereiter, & Scardamalia, 1993). One strategy for evaluating the process of knowledge building is to analyze what types of questions learners are engaged in (e.g., Oshima, Scradamalia, & Bereiter, 1996). Chan et al. (2001) analyzed questions that high school students had in their learning on the plate tectonics theory. They found that the high school students came to deal with higher qualities of questions as they proceeded their learning, and that the quality of their questions were positively correlated to the level of their final conceptual understanding. The four levels of questions identified by Chan et al. (2001) were as follows:

- *Level 1: Definition questions*. Students just ask the definition of the term or concept. The most typical and initial question in our lesson was "What is a genetically modified food?"
- *Level 2: Factual, topical, and general questions*. The second level is a type of question that reflects facts or general statements. In most cases, when students ask this type of questions, their idea is around some facts or topics. One example in our lesson was "What crops are genetically modified?"
- *Level 3: Puzzlement questions*. When students showed their puzzlement by collecting ideas by different members and recognizing some gaps among the ideas, their puzzlement was identified as level 3. In our lesson, after learning advantages and disadvantages on GM foods, they recognized some gaps between pros and cons. They could not figure out what further questions they should pursue for filling the gaps, but thought that the filling the gaps was important to them.
- *Level 4: Explanation-based questions*. When students identified inconsistencies or gaps between their ideas then proposed articulate questions for solving the problems, their questions were identified as level 4. Students could recognize the problem they had, and decompose the problem into tasks or questions that they should work on in the next step.

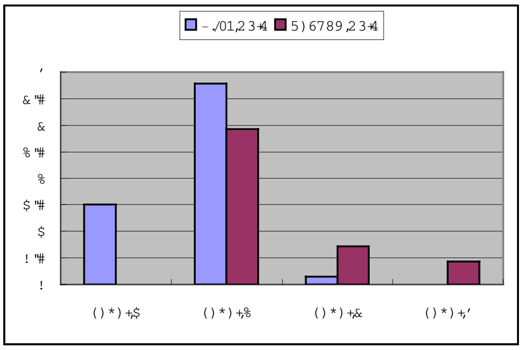

Figure 1. Mean Frequencies of Notes with Different Levels of Questions.

Two independent raters evaluated students' discourse in their notes. The agreement between the raters was .82. Their disagreement was resolved through their discussion. Frequencies of notes with different levels of questions generated by 14 groups of students were counted in the first and second half stages of their learning (see Figure 1). A 2 (Stage of Learning) X 4 (Level of Question) ANOVA on the note frequencies showed the main effect of Level of Question, $F(3, 104) = 29.3$, $p < .01$, and the interaction effect, $F(3, 104) = 3.5$, $p < .05$. The main effect of Level of Question manifested that students generated significantly more Level 2 questions than others either in the first or the second half of their learning. The interaction effect further manifested that they generated Level 1 questions significantly more in the first half of learning than did they in the second half. In sum, the statistical analysis on the frequency of different levels of notes students generated during their learning suggested that questions in their discourse on Knowledge Forum® was changed toward higher levels as they proceeded their learning. In a few notes, students were engaged in high quality of knowledge building activity through their explanations on what they had learned. In many notes, on the other hand, students were still concerned with factual or topical questions.

Students' Activities Related to Knowledge Building Determinants. During their discourse on the ideas on and off Knowledge Forum®, students were encouraged to consider relations among ideas and to propose new ideas from superordinate perspectives. Based on their own concept map, students elicited three issues they had to pursue: (1) "What are GM foods?" (2) "Why are they being developed?" and (3) "Do we have them in Japan?" The three issues were pursued by several small groups in different views. After their studies on the three issues, they shared their ideas and new understanding between groups in different views and gave comments on each other's notes. Their comments led note authors to further revise or add new ideas on the commented notes. Finally, in a view called "GM foods conference," students expressed their decisions on which position (positive or negative) toward GM foods and reasons for their decisions. A few groups of students manifested high quality of discourses on their decisions with reasoning elicited by high levels of questions (i.e., explanation-based questions). Here, we describe their discourse activities to figure out how students conducted their learning as knowledge building.

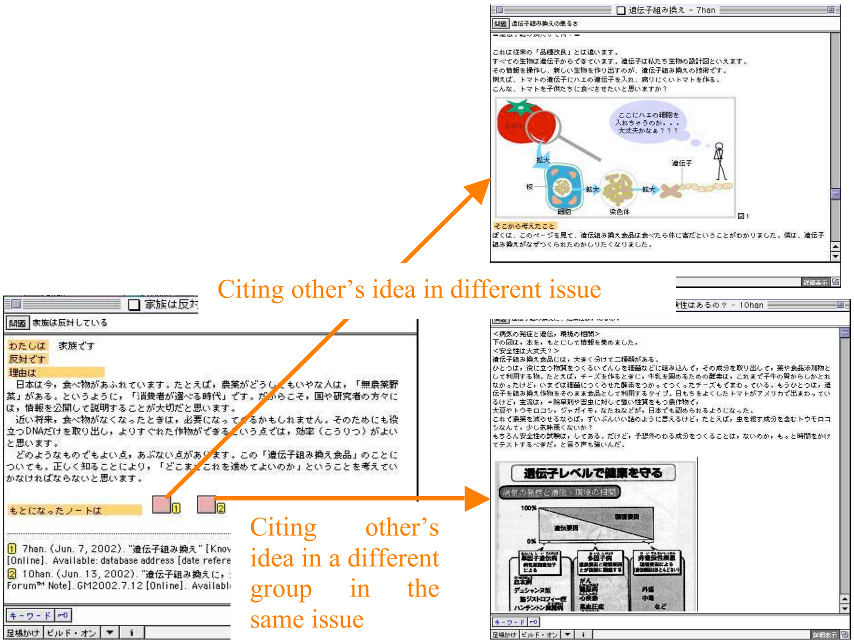

Figure 2. An Epistemic Agency for Knowledge Building Seen in Knowledge Forum® Discourse.

Students who engaged in discourse with Level 4 questions exerted the *epistemic agency* for knowledge building by effectively using functions prepared in Knowledge Forum®. An example of discourse by Group 14 is seen in Figure 2. The group expressed their negative position toward GM foods in the "GM foods conference" view. Their reasoning to make their decision was constructive rather than providing evidences that GM foods are not safe. In their discourse, they used three different idea resources. First, they used *their own idea* for their reasoning. Before expressing their ideas on GM foods in the conference view, they had studied how ordinary customers thought about GM foods by their interview research at a supermarket. Their conclusion was that Japanese customers could choose GM foods or organic ones with their preference in our current situation of food provision. Second, they also referred to *another group's idea on the same issue* to confirm their decision. Furthermore, they described how we can develop GM foods to provide good qualities of food products by citing *an idea in a note by a group that had studied another issue*, "Why are they being developed?". For group 14, the problem that they decided which position they should take toward GM foods was not a simple choice by showing their preference, but they recognized the problem that they had to consider different idea resources on GM foods to comprehensively understand GM foods. In other discourses identified as Level 4 question-based, we found the same tendency that students attempted to build structures of arguments with ideas from multiple perspectives.

Discussion

In the first year of our design study, we implemented four pedagogical design principles to consider design elements in a lesson plan on GM foods. Our analysis on student learning activities showed some positive findings and problems we have to further consider. First, the analysis on the quality of discourse in notes on Knowledge Forum® suggested that students succeeded in improving their quality of discourse as they proceeded their learning. This phenomena is not expectable in ordinary classroom learning. In the ordinary class, students recognize that they complete their learning in the end of the unit of a lesson. Therefore, students usually do not have further questions on their study topic. In our designed lesson, students saw their learning as progressive problem solving and continuously improved their discourse by generating higher qualities of questions. As we found in the ANOVA on frequencies of notes with different levels of questions, however, the tendency was not sufficiently strong in that we could not find a significant differences in note frequencies with Level 3 and 4 questions between the first and the second stage.

The descriptive analysis on students' discourse on Knowledge Forum® was conducted to further consider how more students can be involved in knowledge building discourse. The result manifested that students identified to generate Level 4 questions in their discourse made use of multiple ideas by referring to other groups' notes in different issues to construct arguments for their decision making. Thus, design elements based on our pedagogical principles (e.g., idea-centered discourse on Knowledge Forum®, and the activity and task structure) did successfully scaffold student learning as knowledge building.

The Second Year's Design Study

The Classroom Description

In the second year, the same teacher was in charge of the lesson for another fifth grade classroom on GM foods. The characteristics of students were considered to be similar to that in the first year. Thirty-five students (18 females and 17 males) participated in the lesson as part of their curriculum through 35 class hours.

Progressive Refinement on the GM Foods Lesson

The refinement on the lesson plan was discussed by the design team from the two perspectives: (1) refinement on our pedagogical design principles, and (2) refinement on design elements. Based on results of our analysis in the first year's design study, we concluded that our pedagogical design principles were effective but we could further refine design elements for more students to engage in their learning as knowledge building. Here, we describe how we refined our design elements in the second year.

Consequential task structure: From the GM foods conference to the consensus meeting. In the first year, the consequential task for students to challenge with their understanding on GM foods was how they as customers deal with GM foods in their real life. As we described in the section of the first year's design study, some groups of students recognized that the task required them of exerting their *epistemic agency* for knowledge building, i.e., monitoring what ideas they as a classroom community had and considering how they could integrate different perspectives to advance their understanding. However, the task requirement was not found to be articulate enough for most students to exert their *epistemic agency*. In the second year, we changed the consequential task from their decision making to the consensus making. In our real life, the Ministry of Health, Labour, and Welfare regularly opens the consensus meetings on GM foods for ordinary citizens. The main purpose of the consensus meetings is to articulate opinions customers have after learning about GM foods (i.e., This is what students did in the first year), and to consider what problems or issues should be further considered and solutions to the problems. In the consensus meetings, there is a coordinator who should manage progressive and productive discourse by customers by providing scientific evidences and helping them organize their arguments. We introduced the concept of the consensus meeting to students and encouraged students to engage in their learning by playing a role of coordinator of the consensus meeting. Students were expected to consider globally multiple perspectives on GM foods and propose solutions to problems customers are currently concerned with. Student activity required by the consensus task was considered to more directly elicit student *epistemic agency*.

Student learning activity structure: From three sub-projects to one big project. In the first year, students were divided into three sub-projects in each of which several groups of students conducted their research and reported their ideas and information in their project view. In the "GM foods conference" view, students were expected to collect ideas from the three different views to make their reasoning for their positions toward GM foods. The result of descriptive analysis on student discourse in the conference view manifested that only a few groups of students referred to ideas from multiple views. Thus, the result suggested that relatively large number of students were not using their colleague's idea resources effectively. In the second year, therefore, we refined the student activity structure by not dividing them into sub-projects but having them study on the basics of GM foods in the single view and share ideas with each other.

Evaluation of Student Learning as Knowledge Building

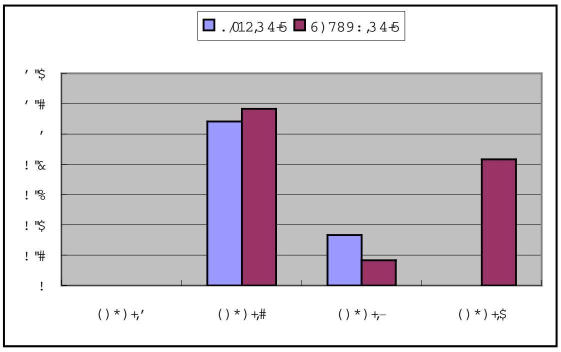

Figure 3. Mean Frequencies of Notes with Different Levels of Questions in the Second Year.

Qualities of Students' Questions Identified in Their Discourse on Knowledge Forum®. Students-generated notes were categorized into one of discourses with the four levels of questions by two independent raters. Their agreement was .93. Their disagreement was resolved through their discussion. Note numbers were counted, and a 2 (Stage of Learning) X 4 (Level of Question) ANOVA on note frequencies was conducted (see Figure 3). There were found to be a main effect of Level of Questions, $F(3, 88) = 12.1$, $p < .01$, and the marginal interaction effect, $F(3, 88) = 2.6$, $p = .06$. The results were summarized that students constantly generated more notes with Level 2 questions across the two stages of learning than other types of notes, and that they generated more notes with Level 4 questions in the second half than did they in the first half.

Students' Activities Related to Knowledge Building Determinants. In the second year, students were encouraged to propose solutions for people from different perspectives to make their consensus in the "Consensus Meeting" view. With our designed scaffold labels for their discourse, students attempted to make their reasoning by collecting ideas from their previous views as well as the current view. Since note numbers produced by students in the two years were different, we did not directly compare mean frequencies of notes with different levels of questions. A comparisons of proportions of groups that produced discourse with Level 4 questions between the two years (six of fourteen groups in the first year vs. six of twelve groups in the second year) did not manifest a significant difference, $\chi^2 = .13$, $df = 1$, $p > .05$. A remarkable finding was, however, seen in the comparison of proportions of notes in which students attempted to use ideas from multiple perspectives by citing others' notes. Chi-square analysis of note numbers showed that students in the second year produced significantly more notes considering multiple ideas (12 of 26 in the "Consensus Meeting" view) than did those in the first year (8 of 58 in the "GM Foods Conference" view), $\chi^2 = 10.36$, $df = 1$, $p < .01$. Thus, it was found that more students exerted the *epistemic agency* for knowledge building in the second year.

Discussion

Our refinement on the lesson by improving design elements, particularly the consequential task structure and the student activity structure, was found to be successful for improving student learning as knowledge building. In the second year, the improvement of student discourse in their notes was more robust than that in the first year. They did not only ask Level 1 question like "What is the genetically modified foods?" but also added more argument to produce higher levels of questions. The difference in note numbers between the first half and second half was found in the category of Level 4 questions. As discussed previously, the new consequential task requirement to propose solutions for people with different perspectives to make their consensus triggered students' *epistemic agency* to integrate ideas from multiple perspectives. The result of the analysis on numbers of notes in which students attempted to use multiple ideas supports our argument. In the "Consensus Meeting" view, significantly more notes were produced including multiple ideas. The activity structure, one big project, might have students more easily reflect how the classroom proceeded their learning. They did not need to switch back and forth different views for monitoring what ideas their colleagues were interested in or worked on.

GENERAL DISCUSSION

Our design studies across two years were aimed at designing a lesson plan for knowledge building in the period for the integrated study. We transformed metaprinciples on knowledge building into four pedagogical design principles for the classroom learning. The analyses manifested that our refinement on design elements based on our pedagogical design principles succeeded in facilitating student learning as knowledge building from the first year to the second. In this section, we again go back to the metaprinciples for discussing how our pedagogical design principles transformed the classroom into a knowledge building community.

"Real Ideas, Authentic Problems," "Improvable Ideas," and "Idea Diversity." Our pedagogical design principle on putting students' ideas at the center of the curriculum was successfully transformed into our lesson design across the two years. Students started their learning with what they had already known on the study topic

then proceeded their learning based on their own ideas and others'. Their ideas were externalized as discourse in notes on Knowledge Forum® and shared for further knowledge advancement.

"Rise Above," "Epistemic Agency," "Constructive Uses of Authoritative Sources," and "Knowledge Building Discourse." For triggering students' *epistemic agency* for knowledge building, we designed the lesson so that students were required of expressing their ideas through their discourse in proceeding their learning with the consequential task. In structuring arguments in their discourse, several scaffold labels (e.g., leading sentences, and headers representing thinking steps) were introduced to students. As a result, it was found that students were more likely to engage in knowledge building discourse (identified as discourse with Level 4 questions) through our refinement on the task structure and the activity structure from the first year to the second year. In their knowledge building discourse, students were using scientific evidence or archives from book references as conceptual artifacts (Bereiter, 2002) for advancing their reasoning. However, structuring collective ideas at the classroom as a whole was still managed by the teacher. Students were encouraged to rise above their individual group ideas by editing their views. In the next step of our progressive refinement, we like to consider design elements by which the teacher could take over the role of editing views (i.e., two-dimensional maps of different groups' ideas in issues students are concerned with) to students themselves. By sharing ideas in notes on Knowledge Forum®, students were found to intentionally engage in such an epistemic discourse in the classroom as a whole.

Table 1 shows an example of discourse seen in the classroom in 2002. In the discourse happening in the classroom, students were concerned with how to report their ideas developed through their groupwork. A student (Student 1) raised an issue that her group had opposite ideas to each other on GM foods. She told that it was problematic to report ideas as groups. The teacher accepted her problem in organizing a view on Knowledge Forum®, and further searched for ideas on how to solve the issue. Student 4 proposed that they were going to report individually based on their discussion in their groups. What we found from the discourse here is that students were acting as epistemic agents for their own learning. This type of epistemic agency was found across the two lesson units frequently but inconsistently. Students considered how to proceed their learning task by task, but did not consistently monitor a course of their learning in units. We have to further design elements so that students are naturally engaged in working on the management of their learning with their ideas represented on the knowledge medium. Editing the view may be a candidate element for us to ask them to do for facilitating their epistemic agency.

Table 1. An Example of Discourse by Students in Discussing
How to Report Their Ideas in the GM Food Conference View.

Teacher	OK, [Student 1]. You have a question, don't you?
Student 1	Do you think that we are going to report ideas by groups?
Teacher	Yes, I do so.
Students 1	Well, if we are going to do so... When [Student 2] and I have the positive idea and [Student 3] has the opposite one, do you think that we have to choose one of the two?
Teacher	That's a really good question. I understand your concern very much. It is reasonable for us to predict that members in a group will have opposite ideas to each other. Some says positive whereas the others say negative... Do you have an idea on how to solve this issue, [Student 4]?
Student 4	I have an idea related to the question by [Student 1]. If we have the opposite opinions to each other in a group. why do not we report our ideas as individuals on the GM Food Conference View?
Teacher	Oh, you said that we report individually. It may be a way for us to go. I think that it is quite reasonable. Do all understand his idea? He proposed that we are going to report ideas individually if we have opposite ideas to each other so that we cannot report one note as a group. ...

"Community Knowledge, Collective Responsibility," "Democratizing Knowledge," and "Symmetric Knowledge Advancement." The student activity structure with collaborative learning within and between small groups made it more naturally possible for students to express their ideas to other members in their groups and their group ideas to other groups either on Knowledge Forum® or in the classroom. Our analysis of students' discourse in highly qualified notes manifested that they attempted to refer to ideas from multiple sources, and to take several different perspectives into consideration.

"Pervasive Knowledge Building," and "Embedded and Transformative Assessment." The pervasiveness is our final goal. It is not reasonable to expect that students can always have their tendency to deal with their

learning as knowledge building after their engagement in our designed lesson in such a short period of time (20-30 class hours). Therefore, we cannot evaluate if our design could satisfy this determinant. One surprising finding for us was that a few students reported how their learning in our designed lesson had been different from those they were usually taking in the classroom in the post interview. The assessment is another big issue for us to consider in the next refinement. In our design studies in the reported years, the assessment activity by students was designed by us. The teacher encouraged students to do their self assessment on the progress in their learning at the benchmark lessons. The more ideal situation should be that students can propose their colleagues or teacher to have opportunities to assess their progress through their regular monitoring. This is the highest level of metacognitive activity students can be involved in. We need to figure out the developmental trajectory of student *epistemic agency* for doing their own assessment through repeated refinement on our lesson.

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