

Problem Solving Approaches in Mathematics Education

Problem Solving Approaches in Mathematics Education as a
Product of Japanese Lesson Study¹

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What is the product of lesson study? Lesson study is a scientific activity for teachers based on the methodology introduced 1880s. In Japan, research topics for lesson study are usually shared through the regular reviews of curriculum and research movement by several societies. As a result of teachers' challenges on the topics of lesson study, several local theories of teaching were shared. 'Problem Solving Approach' has been known as Japanese teaching approach and is a well known theory of teaching for developing children who learn mathematics by/for themselves. It includes teaching about learning how to learn. Additional important products of lesson study are theories for curriculum, described in teacher's guidebooks as a number of technical terms which are only used by teachers and math educators for sharing pedagogical content knowledge.

Key Words: Japanese Lesson Study; Problem Solving Approach; Pedagogical content knowledge; History of Lesson Study.

Introduction

What is the product of lesson study? There are a number of research efforts for making clear the function of lesson study from the viewpoint of professional development in response to the report 'Before it's too late: A Report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century' [The National Commission on Mathematics and Science Teaching for the 21st Century, 2000]. On the other hand, on the context of APFC-HRDWG Project 'Innovation of Mathematics Teaching and Learning through Lesson Study' (APEC-HRDWG Lesson Study Project Website) since 2006, in every evaluation meeting, project overseas, Maitree Inprasitha and Masami Iwata, used to explain the basic meaning and significance of lesson study. Some of major questions which we received are if it is the study there is some evidence with numerical data such as the comparative study of classroom practice with the scientific analysis of video tapes such as TIMSS video study (1999 Video Study of Eighth-Grade Mathematics Teaching). In this paper, we would like to make clear the meaning of 'the study' based on Japanese experiences more than 100 years began by Normal School (Wakabayashi, T., Shirai, T., 1883) from the influence of the Pestalozzi method.

In the past ten years, the movement of lesson study focused on teacher's professional development on the context of 'Before it's too late'. There are a number of researches who try to evaluate the professional development of teachers from the view point of pedagogical content knowledge (See such as Hall, H., Ball, D., and Schilling, S., 2008). On the other hand, in Japan, lesson studies have been usually done for developing children by teachers and result of lesson studies usually theorized and applied for improvement of textbooks and curriculum. In the case of Japan, Pedagogical content knowledge (PCK), defined as a kind of professional knowledge

can be developed as a teacher based on pedagogical knowledge and content knowledge could be learned at the university (Shulman, 1986), is not only limited teachers' professional knowledge but also theorized as the theories of mathematics education and can be also learned in universities, through journals and guidebooks (Isoda, M., Nakamura, T., 2010). On this context, lesson study in Japan is a scientific activity for teachers who try to develop their own theories for developing and sharing good practices. The products of lesson study are not only limited to what each participant learned from the class and the post-class reflective discussion for developing each participant's PCK but also we develop the theory for mathematics education. Each participant try to reproduce the observed class at his/her class with their own developed theories for practice in each of their contexts. Even if, on the personally, each of their theories is just a description of their PCK which is working as their local theory in each of their practices, it will be understandable and sharable as a theory for teaching because Japanese teachers shared national curriculum standards and textbooks and these are hidden grounds for their PCK. The regular revisions of curriculum supply national research topics for lesson study (Isoda et al.; 2007). As a result of teachers' challenge of lesson study on the same topic from a school to national level, local theories are integrated into a shared-common theory of teaching. Teachers' journals and academicians who usually participate in lesson study support this theorization through proposing necessary technical terms for improving practice. As for the consequence of a hundred years of lesson study, Japanese math-educators and teachers shared two types of theories for teaching.

Firstly, the *Problem Solving Approach* has been known as a Japanese teaching approach, which was well described by Stigler & Hiebert (1999). It is one shared theory for developing children who learn mathematics by/for themselves in Japan. It includes teaching about learning how to learn, which also means that children learn how to develop mathematics by/for themselves.

Secondly, another important product of Lesson Study consists of theories for curriculum, described in teacher's guidebooks in the form of a number of technical terms which are only used by teachers and mathematics educators for sharing pedagogical content knowledge. For example, in the U.S., the Cognitively Guided Instruction (CGI) Project showed us the evidence of the different ways of counting types for addition and subtraction from the 1980s [Carpenter, T.P., Fennema, E., Franke, M. F., Levi, L., Empson, S. B., 1999]. In the case of Japan, counting types and the problem situations were categorized after World War I and before World War II. In 1960s, there was a confrontation on the definition of multiplications between fixing the limitations of dimensions (like Euclid) which was supported by some teachers union and going beyond the limitation (like Descartes) which was based on the national curriculum. Proportional number lines have been introduced to overcome the limitation. From this confrontation, Japanese national curriculum clearly enhanced the extension and integration as for the principle of curriculum sequence to develop children for learning mathematics by/for themselves.

Both major achieved theories are well described in the Special Issues of Journal of Japan Society of Mathematical Education for EARCOME 3 (Isoda, M., Nakamura, T., 2010). The origins of technical terms are different depending on each term. For example, various ancient mathematics such as Chinese mathematics and Arabic mathematics used to describe the methods of solutions depending on the problem types. Thus, historically, analyzing the problem type itself used to be a mathematical activity. Distinguish of division between Partitive division (Tobunjyo) and Quotative division (Hoganjyo) related with Japanese Language. On the other

hands, the history of problem solving approach is comparatively easy to find the origin.

In following chapters to explain the meaning of Lesson Study and the emergence of the theories, firstly, the meaning of products of Lesson Study is elucidated, and secondly, a brief history until the problem solving approach is illustrated. Thirdly, using a case of a school level lesson study project, the practical theory of teaching for the Problem Solving Approach is explained. It is a sample product of lesson study on the problem solving approach.

Lesson Study and the Products of Lesson Study

What is Lesson Study?

There are various ways in which Lesson Study is understood. In many English articles, especially in the U.S., Lesson Study is understood as a school-based approach to enhance professional development to improve teaching. In the case of Japan, there are many more perspectives about Lesson Study. Japanese Lesson Study is recognized with the following features:-

1. **Process/Lesson Study Cycle:** Plan (Preparation: *Kyozaikenkyu*), Do (Observations) and See (Discussion and Reflection) activities involving with other teachers.
2. **Various Dimensions of Open Classroom:** Personal (by master teacher), Whole School, Regional and National lesson study but Systematic.
3. **Theme of Lesson Study:** Study Topics and Objective are different. Study Topics such as Developing Mathematical Thinking, Learning for/by themselves in relation to development, reform or improvement. Study Topics are different depending on the dimensions of the open classroom and teachers' groups. Objective is specified at each class in relation to the curriculum. In the case of Japan, the objective is often described by the sentence 'Through A, students learn/understand/enable to do B' because the Japanese curriculum asked teachers to teach learning how-to and focuses on achievement as an outcome.
4. **Lesson Plan:** The format is not fixed but is usually developed or improved depending on the study topic. Some countries recommend a set of national lesson plans as a part of curriculum, but Lesson Study is implemented to overcome new challenges and this generates new lesson plan formats and new teaching approaches.
5. **Teachers' mind:** Lesson Study is conducted by teachers for developing students in a classroom and to make each student develop by him/herself, not for researchers who just observe a classroom through their own lens. Even though researchers participate in Lesson Study as part of their own research, if they do not understand the teacher's objectives for developing children, and if they do not work together with them, then it is just an activity of a social scientist as an external observer. In this sense, Lesson Study recommends that researchers be like teachers who propose improvements for the class, and teachers be like researchers who analyze children's understanding.
6. **Results:** Lesson Study usually considers achievement in relation to the study topic and objective. At the same time, the aims of Lesson Study varies depending on the participants and are not always the same as seen in the following: Model teaching approach, new ideas for traditional approach, understanding objectives, what students learned before the class, what students learned and could not learn in the class, teachers' values, students' values.

professional development, ideas for the curriculum reform, theory of mathematics education, and so on.

7. **Sequential experience for sharing the heritage:** Lesson study cycle continues beyond the teachers' generation. It's usually opened for newcomers and changes experienced bearers. On this context, similar experiences usually are recognized as new experiences with challenges. That is the reason why lesson study develops the learning community and recognized re-productive science.

One of the most sharable products is a description of model approaches. These guidebooks for teaching contents and teaching approaches have usually been written by teachers and edited by math-educators for theorization and consistency. In these twenty years, videos have been used for sharing good approaches by making them more visible (APPC-HRDMC: Lesson Study Project Website). In some countries, a model approach sometimes means a teaching manual with the sequence of teacher's questions and children's answers which are expected to be followed by every teacher such as hamburger shops. On the other hand, in the case of lesson study, it is nature of that to work beyond a model because lesson study usually includes a proposal to develop something new in their group based on their own theme of lesson. And usually, new challenges include some difficulty that should be overcome. Thus, on the context of lesson study, a model approach means an illuminating approach and major resources for adapting a model into each teacher's classroom. There are several ways of adaptation. One way is based on the shared theory. Based on the theorization by math-educators such as developing mathematical thinking, the special format of lesson plan or classroom activity style usually developed. Teachers try to implement their class for developing mathematical thinking through using proposed format. One of other ways is just use the task or ways of problem posing such as open-ended approach. Ways of adaptations are depending on the objective of lesson study. Some of them related with trying to show more evidences for theories. Some of them related with developing children more actively in their classrooms. All activities includes new challenges for teachers because they try to implement it in their specified classrooms. In these meanings, lesson study is a reproductive science for teachers.

Lesson study has diversity from personal level to national level and produce various type of teaching approaches. For example, figure 1 shows a bird-eye view with three types of teaching approaches. Even though many Japanese classroom videos indicate problem solving approaches and more dialectic approaches, many of Japanese elementary school teachers teach mathematics with injection approach which enhance explained by teachers and exercised by children because they are not specialized in mathematics. Thus, each elementary school set the theme of school level lesson study with problem solving approach because it is a good target for untrial teachers.

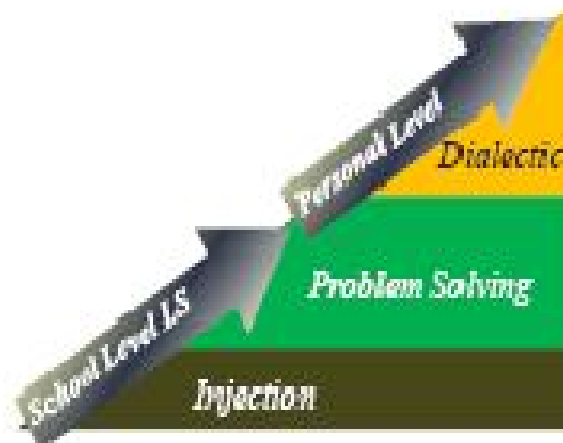


Figure 1. Challenges of the elementary school teacher.

What are the Products of Lesson Study?

There are no limitations on the number of products of Lesson Study. The APEC Lesson Study project since 2006, has been engaging in Lesson Study to develop good practice for enhancing mathematical thinking in 2007, mathematical communication in 2008, and assessment in 2010. The project aimed to spread Lesson Study to improve teaching practice and mathematics educators in Asia Pacific Economic Cooperation (APEC) economies have been involved in expanding the Lesson Study community with elementary school teachers. In this context, the project asked the specialists representing their countries the following questions (Table 1) in relation to how Lesson Study has been applied in the 19 participating economies in the APEC project (Isoda & Inprasitha, 2008 in (APEC-HRDWG Lesson Study Project Website)).

Uses of Lesson Study	Percentage of specialists
Useful for improvement of the quality of mathematics education.	100 %
Influence on other subjects	93%
Used for developing innovative teaching approach.	93%
Used for curriculum improvement.	80%
Used for sharing model teaching approaches.	80%
Used for developing teachers	80%
Used for developing students	80%
Used for developing practical/local theories of mathematics education	53%

Table 1 Survey Results by the Specialists from APEC Economies (Isoda & Inprasitha, 2008)

Most of APEC economies have been at an introductory stage for lesson study. In this context, developing theories of mathematics education are still unusual. On the other hand, in some economies such as Japan, teachers cannot recognize the theory of mathematics education

without considering their practice. For them, lesson study is reproductive science and several theorized guidebook itself is the theory for reproductions. The movement to develop the theory of mathematics education for developing curriculum and practice is not limited in Japan. There are researches which have as their objective enhancing theories of mathematics education through practical experiment. Grauwemeijer, K. (2007) explained the process to develop the local theory of teaching (Figure 3). This is a case of Netherland to develop local theory based on classroom experiment on his research into *Mathematics in Context* (Mathematics in Context). Depending on the researches, there are different meanings of theory for mathematics education but, at least, Figure 3 by Grauwemeijer's work is an illuminating case to show its existence in the world.

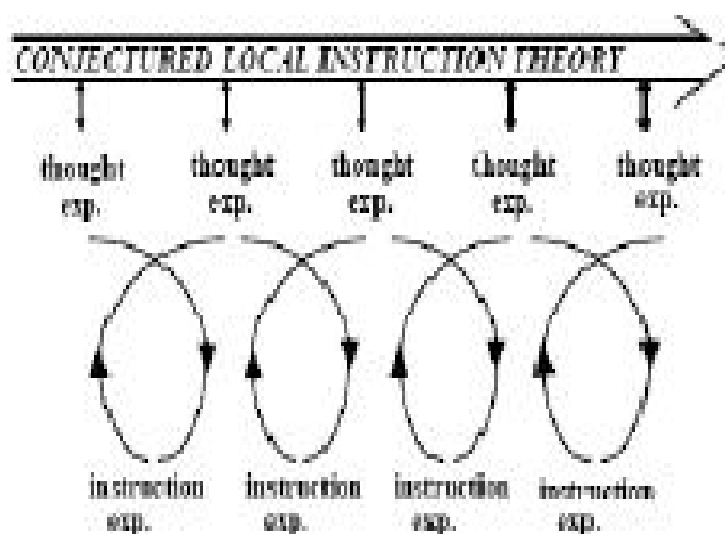


Figure 2. Development of local teaching theory by Grauwemeijer (2007).

History of Japanese Lesson Study from the Viewpoint of the Theme

In the case of Japan, theories of teaching approaches and theories of subject matter in curriculum have been the products of Lesson Study. This tradition is perhaps deeply related to the fact that each Lesson Study is done using study themes such as special topics for Lesson Study. Table 2 shows examples of shared study topics (Nagasaki, 2007; Iwada 2004). On this table 2, the history of Lesson Study has been described with a new theme and a new approach on lesson study for developing children.

Instead of the lecture style, argumentation has been given more focus since the origin of Lesson Study at the Tokyo Normal School (University of Tsukuba) in 1880s (Wakabayashi, T., Shirai, T., 1883). From the beginning, teachers usually used arguments through questioning. Problem posing by children was used as a teaching approach at the attached school of Nara Women's Higher Normal School (Nara Women's University) in 1920s (Shimizu, 1924). Open-ended problems began to be consistently used in the textbook before and middle of World War II (Ministry of Education, 1943). After World War II, these approaches had been theorised again and again on the new issues of curriculum standards. To develop mathematical thinking in 1960s, the prototype of the problem solving approach was well-known in Japan. In 1980s, the

approach began to be widely disseminated. The junior high school textbook based on problem solving approach was published in 1980s. A number of teaching guidebooks explaining how to implement this approach has been in publication since the 1980s. In the following sections, some extracts from history are explained. In 1970's, Japanese mathematics curriculum developed by the principle 'extension and integration.' The principle is also meaningful for problem solving approach because it aimed to teach how to extend and integrate mathematics, too. On the other hand, it is not easy for every teacher who is not math-major and this is the reason why school based lesson study is meaningful for challenging this approach because they can learn the approach from the math-major teachers who exist one or two in school.

Table 2 *Samples of Lesson Study Topics* (revised, Nagasaki, 2007 and Isoda, 2004)

Topic of Lesson Study		
1880s:	Pestalozzi Method and Dialog Method (including argumentation/discussion/dialogue between teacher and students)	Not only limited mathematics.
1910s:	Mathematics for Life (including problem posing)	Not only limited to mathematics.
1930s:	Curriculum Integration in Mathematics (including Open-Ended Problems)	From the 1900s
1950s:	Core curriculum movement based on social studies	Under the occupation after WWII.
1960s:	Mathematical Thinking (Japanese way of New Math)	Related with New Math
1970s:	Open-Ended Approach and Problem Solving Approach	For developing Mathematical Thinking.
1980s:	Problem Solving	Related with the U.S.

The Origin of Lesson Study

Japanese Lesson Study originated in 1872 when the Education Code was established and the Normal School (University of Tsukuba) and the Attached Elementary School (Elementary School Attached to the University of Tsukuba) were established at the same time (Isoda et al., 2007). It began with teachers observing teaching methods in a whole classroom situation. This was first introduced in schools that were outside the temple school culture which used tutorial teaching methods. Teachers observed the ways of teaching to learn how to teach. The Teachers' Canon was published by the Normal School in 1873 which documents the etiquettes for entering classrooms to do observation in order to avoid difficulties during the observations (see Figure 3).



Figure 3. The cover page of the teacher's canon (1873).

The Origin of Developing Students Thinking and Learning by/for Themselves

Occasionally, general educators and educational management researchers may attempt to enhance the function of the professional development on Lesson Study without giving attention to the preparation of subject matter and teaching approaches. However if the focus of Lesson Study does not involve the subject and the teachers' perspective for developing children, then it does not fulfil and achieve the whole meaning of Lesson Study.

The first known Lesson Study guidebook for teachers in Japan which have these features is 'Revision of Teaching' which was published in 1883 (see Figure 4). The Lesson Study topic was on the Pestalozzi methodology of teaching approach for whole subjects, but it was not the same as the original version in German because it was imported from the New York Oswego Normal School and adapted in the Japanese way. In those days, Lesson Study had been introduced in Japan in a top-down way as well as through the establishment of the school system at the initiative of the government.

Another important feature of the first guidebook was the establishment of a model teaching approach through questioning ('*Hatsumon*', as we call it today) for developing students who think by themselves. To enhance a dialogue style of classroom communication in whole classroom teaching, the model approach itself was described by using dialogues such as those of Plato and Confucius. In order to represent the process within a limited number of pages due to the high cost of publication, the model dialogues were recommended to enable teachers to plan their lesson. A protocol to describe social phenomena as is done by current researchers on social science was not developed. The teachers' guidebooks in Japan have been keeping to the custom of using the model dialogue because it is much more reproducible than the social-science-like protocol. From the viewpoint of teachers who are trying to reproduce this approach based on the model approach, the model dialogue description style is reasonable because careful protocol in social science only describes the past as the object of interpretation and does not aim at designing new practice. However, the model dialogue focused on essential part is used for reproducing the class based on the object of the class.



Figure 4. "Revision of Teaching" (1883)

Origins of the Problem Solving Approach

Jingo Shimizu wrote a book, 'Teaching Elementary School Mathematics through Problem Posing' in Japanese in 1924, which explained the innovative teaching approach including the fact that an activity of learning mathematics begins from children's problem posing (Figure 3). In that era, the Japanese Teaching Principle, 'Learning by/for Themselves' had been described by teachers and educators who wrote the teachers guidebook for teaching. Before him, the problem posing approaches were existed but his approach was innovative because he tried to teach mathematics with his approach, consistently. Even if his approach was known in Japan as a new trended of mathematics education at that age through the publication of his book, it was not popularized because the approaches were not possible for cordially classroom teachers.



Figure 3. Problem posing approach by Jingo Shimizu (1924)

Japanese Problem Solving Approach, known as the process through 'posing a problem', 'independent solving', 'comparison and discussion', and 'summary and application', became known in the U.S. through the comparative study on problem solving in the 80s by Tatsuro Miwa and Jerry Becker (1988-1992). It influenced the world through the TIMSS video study in 90s (Stigler & Hiebert, 1999). Becker and Shimada (1997) explained the approach from the perspective of open ended problems. Shimada's idea itself originated in the 1940's. It is a good approach to introduce lesson study in any school (Lupasabita, M., 2006)

Problem Solving Approaches are one of the shared approaches in Japan and developing such a sharable approach itself is one of the long-term results of Lesson Study. Lesson Study is known in the world to be associated with Problem Solving Approach. It may not have been spread if it had been only explained by the lesson study cycle. The problem solving approaches combined with lesson study has spread to the world from Japan through the comparative studies and teacher training programs for developing countries from 1980s, the Japan International Cooperation Agency's projects from 1993 (See, Iwata et al., 2007) and APEC projects from 2006.

Local Theory for the Problem Solving Approach

Each Japanese elementary school usually sets a theme for the Lesson Study project at the school level through the years depending on the demands of national reform movements, teachers and

school district. Major themes of Lesson Study projects at elementary schools are Japanese, mathematics or general topics. General topics are usually related to cross-curriculum topics such as Physical and Mental Health. For more than 30 years, the improvement of mathematics teaching for better achievement has been a major theme of Lesson Study (Isoda et al., 2007). Especially, in these two years, the achievement of Japanese, Mathematics and Science on PISA has been lower due to the 20% reduced curriculum in 1999, then, Mathematics and Japanese are two major subjects in Elementary School lesson study project.

In this context, more than 30 teaching guidebooks for elementary school mathematics have been published, every year, for explaining theories of teaching. Here, for explaining designing strategy of class on Problem Solving Approach and showing the meaning from the improvement of children' performance, the teachers' guidebook titled 'Designing Problem Solving Class with the Basic Standards for Teaching Given by Check Sheets' by Isoda, M., Nobuchi, M and Morita M. (2009), is currently widely used. Characteristic features of this book are following: It is written as the result of school level lesson study project and described for novice teachers who do not know well how to teach mathematics, even if they might have several years of experience. For enabling them to learn Problem Solving Approach it developed several formats of lesson study such as self check sheets for teachers and children. For developing check sheets, many theories written by math-educators were adopted even if they did not have such kinds of lists. Some of lists were also published in Spanish(Isoda & Olfos, 2009).

In Japan, problem solving approaches are common approaches to develop children's ability to think and learn by themselves. For knowing their achievement, there are two sets of national assessment problems. First type focuses on understanding and skills and second type focuses on mathematical thinking including mathematical argumentation. Both sets of problems are developed on the national curriculum standards and the problems of the second type are deeply related with problems solving approach itself. Those problems are also localized for improving the achievements. For knowing the improvement of children's achievements through the school based lesson study, this project preferred prefecture level assessment problems.

A Checklist for Implementing the Problem Solving Approach

Isoda, Nobuchi and Morita developed various check lists for self-evaluation by teachers and children. Table 3 shows an example of lists for teachers used for explaining and sharing the school's local theory of problem solving approach.

Table 3
Lesson Planning Checklist: Self-Evaluation (Isoda & Olfos, 2009)

Problem Posing	Self-Evaluation
1. The lesson sets tasks that can be solved in a variety of different ways by applying previously learned knowledge, and presents the content to be learned.	4 3 2 1
2. The lesson is planned with tasks (problem given by teacher) and problems (problematic from students), and promotes problem (problematic) awareness.	4 3 2 1

3. The teacher anticipated the methods and solutions.	4	3	2	1
Independent Solving				
1. The children can recall and apply what they have already learned.	4	3	2	1
2. The children's ideas are anticipated.	4	3	2	1
3. Inappropriate solutions are predicted, and advice and hints are prepared in advance.	4	3	2	1
4. The teacher, walks around, observes and helps children to ensure that children use mathematical representation to solve the problems.	4	3	2	1
5. Notes are written in a manner such that they will be helpful for presentation as well.	4	3	2	1
Comparison and Discussion				
1. Steps (Validity, Compare, Similarity and Generalization or Selection) are planned for comparative discussion.	4	3	2	1
2. The ideas to be taken up are presented in an order that is planned in advance.	4	3	2	1
3. The method for writing presentation sheets is planned in advance and directions are provided.	4	3	2	1
4. In addition to develop the ability to explain, children are also foster the ability to listen and to question.	4	3	2	1
5. When ideas are brought together (generalized), it is important to experience them by themselves.	4	3	2	1
6. The reorganization or integration of ideas proceeds smoothly from the presentation and the children's communication.	4	3	2	1
Summary				
1. Activities are incorporated that let children experience for themselves the merits of the ideas and procedures that are generalized.	4	3	2	1
2. The summary matches the aims and problems (problematic) of this lesson.	4	3	2	1
3. It is recognized that both correct and incorrect answers (to the task) are good in the formation of their ideas.	4	3	2	1
4. Children are made to experience the joy and wonder of learning.	4	3	2	1

[4: Achieved; 1: Not Achieved]

Behind this kind of lists, there is a local theory of problem solving approach. For example, the difference of problem (task) and problematic (problem) is a key because problematic is necessary for children learning by/for themselves, and it is also related with the objective of the lesson. This is the result of theorization in 1980s and common for teachers who teach mathematics by problem solving approach. If teachers just aim to teach how to solve the task, teaching solution and give them the time for practice are reasonable approach for them. However, through the problem solving approach, we would like to develop children who would like to think by themselves. Problematic is necessary for them to begin thinking. The object of presenting various kinds of answers are not only for knowing how to solve but also enable children to discuss which answers are appropriate.

When the school began to use the lists on their project, most teachers did not understand the meaning of each list, because in the case of this school most of teachers do not know how to teach mathematics well, even if they have a chance to see other teacher's problem solving approach. The lists were functioned to teach teachers how to develop the class for Problem

Solving Approach, Iwoda, Nobuchi and Morita had been developed a number of checklist, such as board writing checklist, lesson plan checklist and children self evaluation checklist such as ways of explaining and using notebooks.

The Achievement of the Lesson Study Project in Mathematics by the School Using Various Checklists

For a school-based Lesson Study project, the school usually has Lesson Study once a month or more. But it is not always fruitful. How can we develop learning community of teachers and good result of Lesson Study as a kind of reproductive science which was done by other people but have to challenge by new teachers? In the school-based approach, leading teachers usually try to show and share accessible teaching models and to develop a good system in which teachers feel that overcoming their challenges become enjoyable. They further recognise the children's development. Checklists are good tools for sharing achievable objectives. Checklists were developed so that every teacher/child becomes aware of the challenges to achieve the model approach.

In the Ozono Elementary School, after the one and half year mathematics Lesson Study project using the various kinds of checklists for mathematics, the children's achievement improved (Iwoda et al., 2009).

As shown in Figure 6, the children's mathematical thinking ability which is a key for learning by/for themselves improved. It shows that the achievement of the children in the 5th grade improved by 15 points in the mathematical thinking test as compared with the average of the whole prefecture. Figure 7 implies that the achievement of school-level mathematics Lesson Study during the one and half year is not only limited to the improvement of children's mathematics achievement, but had also influenced positively the other subjects such as Japanese, science and social studies. It means that the Lesson Study efforts in the teaching approach in mathematics through the use of checklists may influence other subjects. In the Ozono Elementary School, a teacher teaches almost all subjects. The children's awareness of empowerment in mathematics led to the improvement of their interests in learning and developed their wish to study.

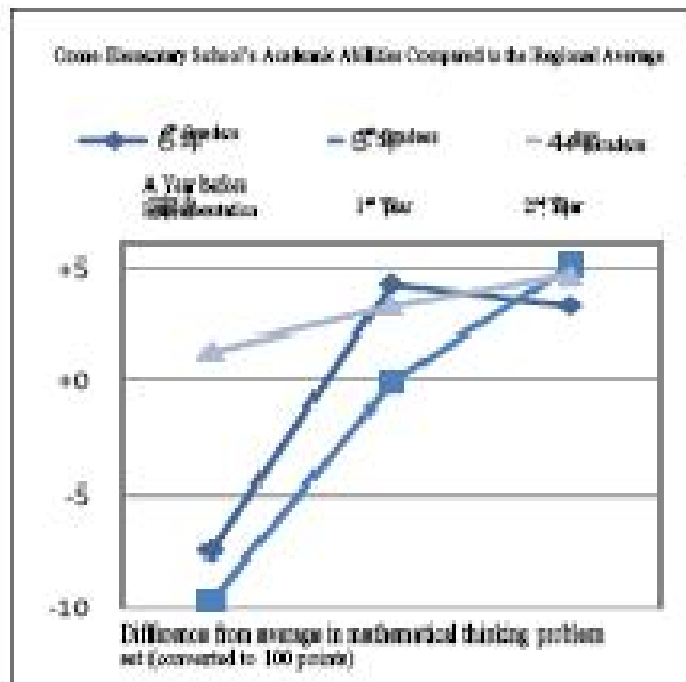


Figure 6. Ozone Elementary School's academic abilities compared to the regional average.

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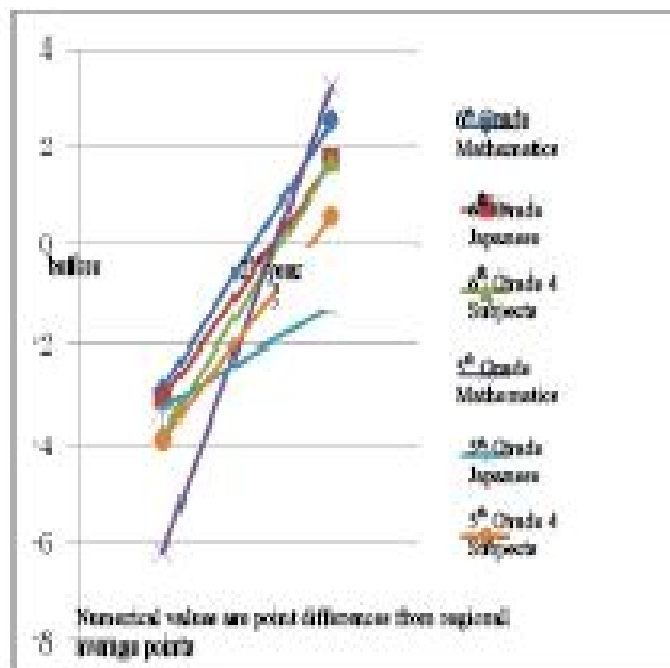


Figure 7. Ozone Elementary School's academic abilities compared to the regional average.

The achievement seems to be the result of Lesson Study using the checklist in the school. To improve classroom teaching, it is important that teachers and children share objectives. Through sharing objectives, the main ideas behind theories such as the Problem Solving Approach and the theory of curriculum were learned. The Ozono Elementary School developed the *Lesson Planning Checklist* based on the theory of problem solving approach (Isoda, Nobuchi & Morita., 2009). The *Children Learning How to Learn* checklist and *Lesson Plan* checklist, and also other checklists such as the way of blackboard planning were also used (Isoda, Nobuchi & Morita 2009). These checklists have also been improved on (Isoda & Olfos, 2009) for use in Latin America. The checklists provided opportunities for children to check by themselves to reflect on the areas of learning that should be improved.

Figure 8 shows the result of self-evaluations by teachers on the lesson planning checklist in order to verify whether their instruction method and the problem solving approach have been appropriate or not. Figure 8 compares the achievement at the start time with the achievement one and a half years later. At the beginning of this research, teachers were not sure of the meanings of the words listed on the lesson planning checklist. By taking on the challenge of this project throughout the entire school for one and a half years, the teachers gained confidence in their instruction method. Through the improvement of teachers' teaching practices through the school's Lesson Study project in only one and half years, teachers' teaching methods also improved and in turn, children's achievement improved even beyond mathematics. This was the result of collaborative lesson studies by Ozono Elementary School teachers.

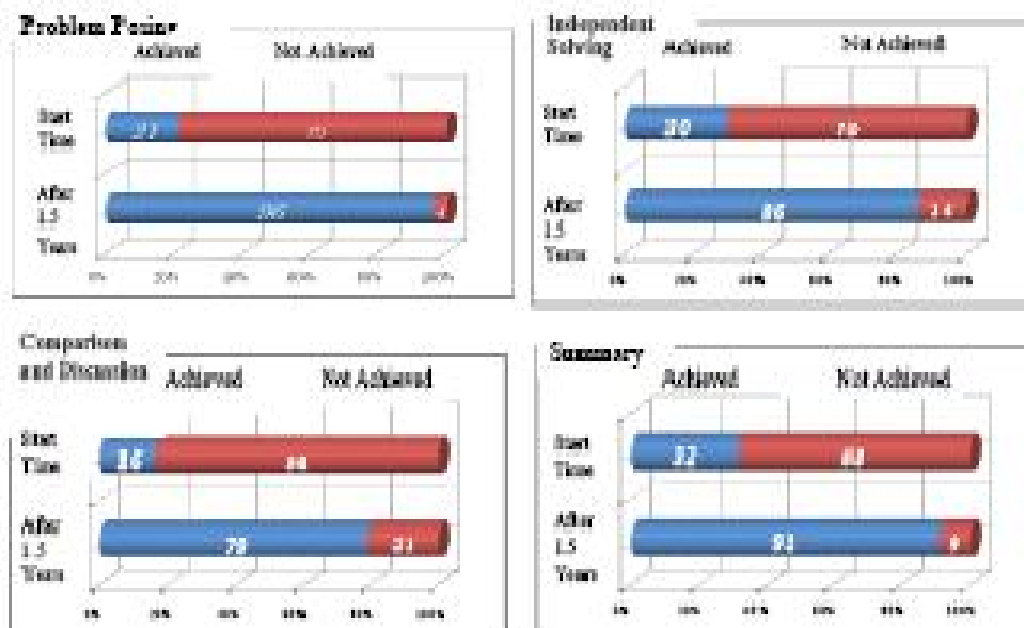


Figure 8. Improvements of teacher Instruction through Lesson Study with checklist.

Final Remarks

To know the various products of lesson study, especially knowing the theory of mathematics education as for the reproductive science of teaching approach, this paper traced the historical development of Japanese Lesson Study in the case of mathematics and explained the development of the theories of mathematics education in its history. This paper briefly illustrated the case of the Ozono Elementary School to explain a case of developing local theories using a school-based approach.

The achievement of Ozono Elementary School is just a case of the school level Lesson Study to implement the Problem Solving Approach. As a number of lesson study activities are completed by school, the teachers begin to develop their local theories of their Problem Solving Approach. These theories are the teachers' theories developed by teachers with the support of researchers or supervisors to improve their daily practice.

From the viewpoint of science, the weakness of the Japanese Lesson Study is that it does not aimed to prove a scientific proposition but aimed to develop children. For example, in Ozono elementary school, there was minimum data collected even if the teachers used various checklists in their Lesson Study activity because the use of the checklists was to know the objectives of teaching among teachers and children but not aimed to prove the proposition that checklists are useful or not. This is the reason why we take the minimum of data which is necessary to develop children, not to prove the scientific proposition itself. In Lesson Study, the progress is evaluated by classroom observation, especially by observing how children develop. Even if the proposition is not qualified by data, the development of children which is directly observed by a number of teachers is more reliable for teachers. The weakness for the scientific researcher becomes the goodness for teachers who are engaging in lesson study as the reproductive science. Teachers have their own approach to theorise their practice and Japanese Lesson Study is about the methodology to develop a local theory of teaching.

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