Master Thesis

Development of a SqueakToys-based Educational Model Aiming for the Acquisition of Mathematical and Scientific Concepts

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数学的・科学的概念の習得を目指した SqueakToysによる教育モデルの構築

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内容梗概

現在の日本では、子どもたちの問題発見能力や課題解決能力といった力を育成することが、教育改革において求められている。この改革のひとつとして、「総合的な学習の時間」と呼ばれる新しい教科が小学校では 2002 年度より設立された。この教科ではコンピュータが重要な役割をもつと考えられているが、この教科の学習目標の意図に沿ってコンピュータを利用する授業方法はまだ確立されていない。

問題解決能力などのさまざまな力を学ぶ方法として、「ものづくり」を通した学習が有効であると言われている。ゆえに我々はコンピュータ上におけるものづくりを通じた学習に焦点をあて、SqueakToys を用いた教育モデルを考案する。SqueakToys はオブジェクト指向型言語である Squeak で書かれた、GUI を通したプログラミング環境であり、子どもでも簡単に自分のアイディアを表現できるものである。

SqueakToys を用いた教育実践は、すでにアメリカで行われている。我々はまず、日本の小学校において SqueakToys を用いた教育モデルを導入した際の有効性と問題点を調査するため、事前実験として京都市立の小学校にてアメリカで開発されたカリキュラムを用いて課外授業実践を行った。実験の結果、子どもたちは創造的なプロジェクトを作り、SqueakToys を使うことを楽しんでいたため、子ども視点で見れば教育的に効果があると考えられた。しかし、教師の意見をまとめると、SqueakToys を用いた教育において、子どもたちが何を学び、そして教師がどのように教えていけばよいのかが分からず、授業を行っていく自信がないという否定的な見解も多くみうけられた。

そのため我々は、カリキュラムとは子どもたちが何を学ぶのかということを示す「学習目標」と教師が授業を行うために必要な「教材」から成ると定義した。そして、どのように子どもたちが数学的・科学的概念を学ぶのかについて、ものづくりにおける学習過程との対応を明確にした。このようなカリキュラムをいくつか開発し、2004 年度はこれらの評価を行う実践を、放課後の課外授業として行った。本論文では、おたまじゃくしの動きを SqueakToys 上で実現することを目標とした「おたまじゃくしカリキュラム」を例にとり、子どもたちがどのような数学的・科学的概念を獲得したかについて述べる。子どもたちには、科学的概念として、物の「動き」に対する観察力が身についたと考えられ、子どもたちは数学的概念が必要とされるあるひとつの状況について学習していた。

また、SqueakToys を用いた授業において、我々が考えつかなかった創造的な作品を作る子どもがいることが判明した。我々は彼らを「ハイ・クリエイター」と呼ぶことにした。ハイ・クリエイターは、自分のアイディアを他の子どもたちに伝えようとする子どもと、黙々と自分の作品を作ることに打ち込む子どもと２つの種類に分類される。どちらにしろ、彼らは授業において教師、子どもに大きな影響を与える存在である。

SqueakToys を用いた教育モデルの確立のために、カリキュラムを改良する方法について議論を行う。この方法として、我々はハイ・クリエイターのアイディアを反映する方法を提案する。本手法は、子どもたちの進捗状況が授業内で異なる場合において有効であると考えられる。

本研究は情報技術を用いて子どもたちによりよい教育を提供するものであり、輝かしい未来のために貢献するものであると信じる。

Development of a SqueakToys-based Educational Model Aiming for the Acquisition of Mathematical and Scientific Concepts

Kentaro YOSHIMASA

Abstract

The recent improvement of the Japanese standard curricula requires fostering children's ability to find and solve problems more spontaneously. As a part of this reform, a new subject called "the period for integrated study," was established in elementary school in 2002. Although education with computers is thought to be able to play an important role to realize this requirement in the period for integrated study, there are little well-defined curricula and experience how to conduct a class with computers for this purpose.

It is said that the learning process through creation is effective to learn various capabilities, such as problem solving skills. Then we could claim that creation on computers should be much focused on and design an educational model with SqueakToys which has GUI programming environment written in Squeak, an object-oriented programming language. SqueakToys is designed to enable children to create project quickly and express their ideas.

The practice with SqueakToys-based education has been held in the United States of America. In order to investigate educational effects and problems in Japanese elementary schools, we held some workshops with curricula developed in the USA as an initial experiment at two public schools in Kyoto. Since the experiment resulted in making the children create interesting projects and enjoy using SqueakToys, it could be said that our model would have positive effects in education from the children's point of view. However, teachers were not confident to lead the class because they had little idea what children could learn and how teachers would teach using SqueakToys.

Therefore we proposed that curricula consist of the learning goals which show what children learn and the teaching materials which help teachers. In addition, we design how children learn mathematical and scientific concepts through the learning process through creation. Then some curricula were developed and the workshops after school were held to evaluate them in 2004 school year. In this thesis, an effectual Squeak-based educational model will be described from the result of one of our examples, the "Tadpole Curriculum" which learning goal is to simulate the movement of tadpole on SqueakToys to explain what children learned about mathematical and scientific concepts. Children will get the power of observation of the motion as scientific concepts and they will learn one of the cases using mathematical concepts.

In addition, we discovered children who made creative projects that far exceed our expectations in these workshops. We name them "high creators." There are two kinds of high creators. One kind is a child who teaches one's ideas to other children, and the other kind is a child who just concentrates on one's work. These children can have a profound influence on other children in the class.

Then the way to improve curricula is discussed in order to establish the SqueakToys-based educational model. We propose the method reflecting ideas of high creators in the improvement of the curriculum. This method will be useful under the situation in the different progress of the class.

This thesis proposes a way for children to enjoy learning with information technology. We believe our work has made a contribution to make the future bright.

Development of a SqueakToys-based Educational Model Aiming for the Acquisition of Mathematical and Science Concepts

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Chapter 1 Introduction

One important social change happening in the 21st century is industrial re-structuring. This kind of society is often called a "knowledge society." Even in the coming knowledge society, the subject that produces knowledge is none other than people. Therefore, it is an important social issue to promote and cultivate each person's ability, especially for children who play an important role in the future. The Ministry of Education, Culture, Sports, Science and Technology in Japan (MEXT)[1] has been trying to reform the education curricula for the purpose of developing "Zest for Living". The MEXT says the "Zest for Living" consist of 3 parts: the "Academic Ability", the "Rich Humanity", and the "Mental and Physical Health" shown in the Figure 1.

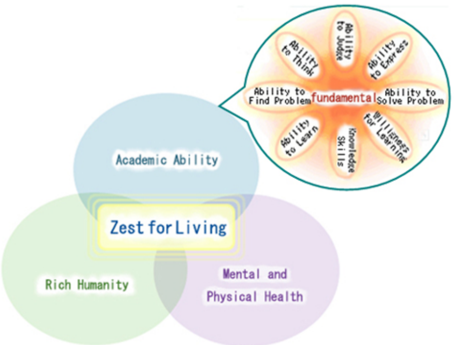

Figure 1: Zest for Living [1]

As a part of this reform, a new subject, called "the period for integrated study," was established for elementary schools in 2002. In this subject, each school is expected to create its own curricula. This may expand the possibility of education. In fact, many teachers are confused because they have little idea about what they should teach.

Some schools are trying to foster "Zest for Living" through creation, considered to be a good way for children to learn various capabilities through process. In addition, it is important to learn about computers because computers are used everywhere in our lives. Since it can be considered that programming is a creation on computers, an education course with programming is a good way to support the promotion of "Zest for Living". However, an educational model through programming has not been established for elementary schools in Japan.

We propose an education model using SqueakToys [2] that has a GUI programming environment for elementary school children. We have been developing curricula that supports the acquirement of logical thinking ability and the understanding of mathematical and scientific concepts. We have been performing workshops using the curricula and evaluating it at public elementary schools in Kyoto under the support of the education board in Kyoto city.

In this paper, the present condition of education in Japan and the advantage of the educational use of SqueakToys are described first. Next, an educational model is examined from the practice results of one of our curricula. Finally, we discuss how to improve our education model.

Chapter 2 Background

In this chapter, we will first present the current situation and requirement of education in Japan. Then SqueakToys and our project will be described.

2.1. The Present Condition of Education in Japan

Children in Japan have a high level of academic ability in the world. However, it is pointed out that the children do not have good study habits [3].

Therefore, there are many discussions on improvement of the education system. One topic includes reflection about the past curricula that consequently led to focusing on cramming much knowledge into students. To foster the abilities that truly enable students to perform important roles in the future, a slogan "Zest for Living" has been raised by the MEXT.

As a more concrete effort to this policy, a new subject was introduced to the Japanese standard curricula in 2002. It is called "the period for integrated study," which requires children to acquire an active learning attitude and to think and solve problems by themselves. Experience-based study and problem solving-based study can be methods for realizing the aim of the new subject. The following two points are declared by MEXT as purposes of this new subject.

1. Letting children get the ability to find, learn and consider the subject by themselves
2. Studying learning subjects covering the multiple traditional courses of study

A specific feature of the period for integrated study is that the MEXT has not prepared a well-defined curriculum like the traditional subjects such as mathematics and science. Every school is expected to define its own curriculum reflecting the school characteristics like local flavor and education policy.

2.2. Education with Computers

As an important curriculum for the period for integrated study, education with computers gathers much attention not only of teachers but also governors. "Information education" has been started in many educational institutes from elementary level to university level. In Japanese high school, a new subject called "Information" has been also introduced to the standard curriculum. On the other hand, in elementary school, any time specifically devoted to information education has not been established and MEXT encourages elementary schools to conduct activities using computers and networks mainly in the period for integrated study.

There are two sides of information education:

- Education about computers
- Education with computers

It is necessary to include both sides in the "Period for Integrated Study." However, it is little implemented now. Typical examples about what is taught in the information education for elementary school children include starting with keyboard typing, sending messages by e-mail and information search by web search engines. There are a lot of experiences on these activities and its know-how is getting clearer.

However, we think that computers can perform more effect in education. The previous examples of computer usage are only to learn how to use the pre-defined functions of the typical and widely used applications. In this way, the process of children's thinking tends to be restricted by what can be done in these applications.

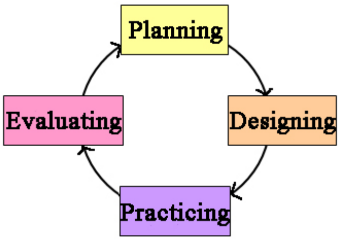

Figure 2: The Learning Process through Creation

On the contrary, we claim that creation on computers should be much more focused on. We think that creation on computers can support children to learn various capabilities, such as problem solving skills through the process in which their ideas are actually made visible to others. The learning process through creation is shown in Figure 2.

The most important issue to introduce creation on computers is that there is no well-defined curriculum, because schoolteachers or governors don't have enough experiences creating on computers. According to the survey conducted by the MEXT in 2003, 72.7% of teachers answered that they can use a computer in their classes [4]. However, a lot of teachers teach only how to use the typical applications or how to search information through the Internet [5]. These experiences are not enough to define a well curriculum for the creation on computers.

We think that programming on computers fits the process shown in Figure 1. To introduce creation to education with computers, there are many candidates for tools that can be used. We decided to choose "SqueakToys" from these candidates. The major reason to use SqueakToys is that it provides a visual programming interface under which even elementary school children can create their own programs.

2.3. SqueakToys

"Squeak" [6] is an object-oriented programming language that inherits most of the features of Smalltalk-80 and is extended to have modern multimedia processing capabilities. Squeak has some features, such as compatibility on major operating systems like Windows, Macintosh, and Linux, development as an open source project, and capability to handle various types of media. Squeak is a common environment which can handle variegated functionalities such as a web browser, a web server and a 3-D manipulation. Moreover, Squeak is based on a simple but powerful architecture, called the "Morphic Framework," inherited from Smalltalk. The Morphic Framework enables every visual object, called a "Morph", to be operated as an object through the visual interface that Squeak provides.

In SqueakToys, the tile scripting function and user interface like generation and operation of objects on Squeak are implemented using the "Morphic Framework." Figure 3 is an example of the tile script function for describing an action of a drawing object. It is possible to make a program with "drag & drops" by combining the tiles that perform operations such as "forward by" or "turn by" or check the conditions such as "isUnderMouse."

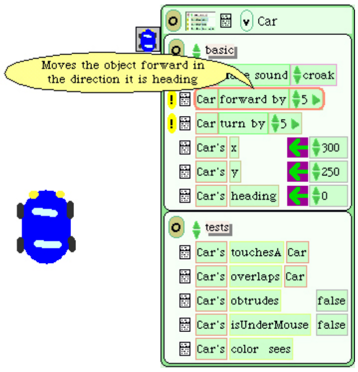

Figure 3: SqueakToys

SqueakToys is designed to enable 8 to 12 years old children to create project quickly and express their ideas in an easy-to-understand environment. SqueakToys is gaining popularity in various places in the world, including the Open Charter School in Los Angeles. Ohshima and Abe have written a multilingual version of Squeak and SqueakToys which enabled us to bring SqueakToys into Japanese classrooms [7].

There have been many experiences in education using programming languages, such as Basic and Logo [8] in elementary schools. Next, we describe the advantages of SqueakToys.

Two kinds of scripts shown in Figure 4 and Figure 5 represent the same function. The graphical program in Figure 4 is made by the tile scripting environment while the program in Figure 5 consists of text. When trying to make a script by text, it cannot be written without knowledge of the programming language. Since the amount of knowledge about the programming language itself becomes very large, it is necessary to spend much time studying the language itself for elementary school children. On the other hand, children can make scripts in a tile scripting environment even if they have no knowledge of the language running behind the tile script. In other words, the tile-scripting environment is less dependent on the knowledge about programming language. Therefore, children can focus their attention on creation.

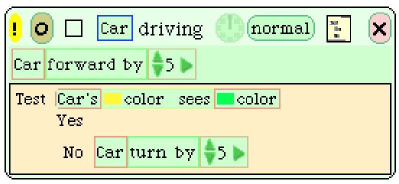

Figure 4: Tile Script

```
driving
    self forward: 5.
    (self
            color: (Color
                    r: 1.0
                    g: 0.968
                    b: 0.226)
            sees: (Color
                    r: 0.032
                    g: 1.0
                    b: 0.323))
            ~~ false
        ifFalse: [self turn: 5]
```

Figure 5: Text Script

In addition, it is important for children to work with interest in an environment where children learn by themselves. Children can keep their interest in SqueakToys because of the following reasons.

- Children can draw a figure that becomes an object.
- Children can show their programming result immediately and visually.
- Children can move objects through the GUI.

These features can be applied to other GUI programming languages, but most GUI languages are specialized for a certain specific function. For example, Tonyu System is specialized in creating games [9]. This is suitable when subjects for creation are restricted to games, but it lacks expandability. In this point, the expandability of SqueakToys is high since all objects are commonly handled as visual objects (Morphs) and it allows possibility that various curricula to be developed.

2.4. Related Work

The practice with Dolittle [10] is performed as the same ideas as ours [11]. Table 1 shows the difference between the Dolittle-based study and our SqueakToys-based study.

Table 1: Compare the Dolittle-based Study and Our Study

	Dolittle-based Study	Our Study
Target Age	Junior-High School	Elementary School
Target Subject	Technical and Domestic-Science Course	The Period for Integrated Study
Main Purpose	To Learn the Principle of Operation of Computers	To Learn Mathematical and Scientific Concepts
Evaluation Points for Children	Understanding of the Programming	Acquirement of the Mathematical and Scientific Concepts
Language	Dolittle	SqueakToys
Description	Text	Tile

The comparison of Dolittle and SqueakToys is described in the paper [11]. The paper says that SqueakToys have tile programming environment but the syntax of Smalltalk is difficult to beginners, so it is described that text programming environment is superior to tile programming environment. We think that the reason why it regards tile programming environment as disadvantage is that its target age is for junior high school students and that its main purpose is to learn the principle of the computer through the programming. We consider that tile programming environment is effective because our target age is for elementary school students and our main purpose is for children to acquire mathematical and scientific concept.

2.5. Practice in the ALAN-K Project

The ALAN-K project was started in September, 2002 by Kyoto University with the Kyoto City Board of Education and Kyoto Software Applications, Inc. in order to investigate the possibility of a computer-supported learning environment [12]. The project is planned to span 3 and a half years. This project is a practical one; five Kyoto-area public schools participate in this project. They include two elementary schools (Gosho Minami Elementary School and Takakura Elementary School), one junior high school (Oike Junior High School), and two high schools (Horikawa High School and Saikyo High School). There is a computer room at each elementary school, which is equipped with 20 desktop personal computers. The schools have a high-speed line to the Internet that allows them to connect to and collaborate with each other.

The SqueakToys-based project is a part of the ALAN-K project. Our visions in this SqueakToys-based project are largely influenced by Alan Kay and his colleagues. Our goal is to develop SqueakToys-based educational model aiming for the acquirement of mathematical and scientific concepts.

Since SqueakToys is for children, it has been mainly carried out at two elementary schools although Horikawa High School has been using it in some classes [14].

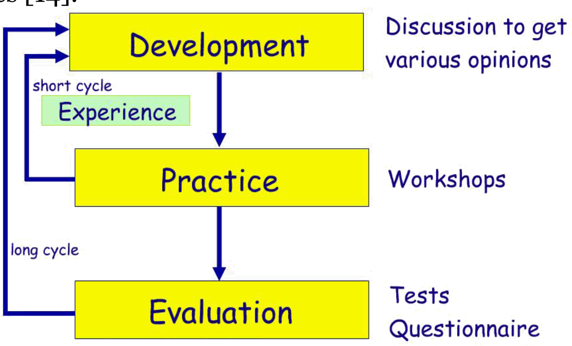

Figure 6: Study Flow

Our advantage is to be able to evaluate our study in real schools. Figure 6 shows our study flow. It takes a long period to evaluate an educational model. However we can make use of our experience to evaluate and develop our educational model.

Figure 7 shows our research positioning.

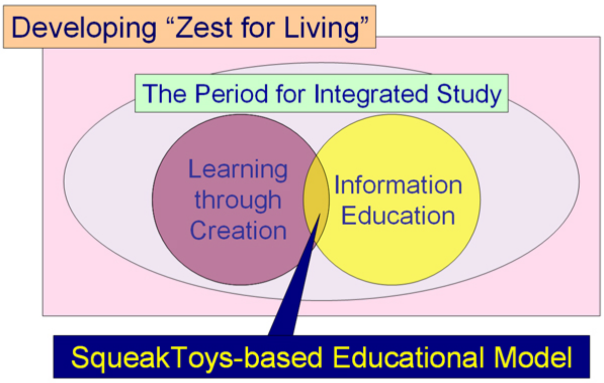

Figure 7: Research Positioning

2.6. Practice in the United States

Practice with SqueakToys had already been performed in the United States, before we decided to start our project. The class with SqueakToys has been held by Ms. B.J. Allen-Conn at the Open Charter School of Los Angeles since 2000. In the class, children gather in front of the whiteboard at first, and she explains what project they will make on the day. Then they start to work on every personal computer. Class sessions are usually 45 minutes long (as well as Japanese class sessions). However, SqueakToys class sessions are 90 minutes because 45 minutes is too short. There are students in the 4th and 5th grade in the class and they take different curricula in the same time.

One curriculum example, "Driving a car" is taken for example. The following examples are enumerated as mathematical and science concepts which children can acquire through this curriculum [15].

- The concept of "x" and "y" coordinates.
- The concept of positive and negative numbers.
- Understanding the concept of "random" as it applies to numbers.
- Understanding the concepts of "mean," "mode," and "median."
- The power of addition: "increase by."

Through the experience at the Open Charter School, it has been considered that SqueakToys has been suitable for children to learn mathematic and science concepts.

Chapter 3 An Education Model with SqueakToys

The aim of our education model is to cultivate children's "Zest for Living" with acquiring the mathematical and scientific concepts in addition to the logical thinking ability by programming with SqueakToys.

3.1. Learning Objective Hierarchy

Learning with SqueakToys requires children to acquire various kinds of skills and competence. Figure 8 shows a hierarchy of learning objectives where Squeak-based classes are conducted.

At the bottom level, basic computer competence like mouse operation and keyboard typing is required to operate a computer itself. Japanese children also have to master Kanji conversion to input Japanese and Chinese characters. The next level is basic Squeak competence that corresponds to application specific operations such as file loading/saving and operating script tiles with mouse and keyboard. Together with this, Squeak skills to make use of tile scripting and control program execution are required to make a program.

These skills and competence are only the basics of learning with SqueakToys. Our main objectives reside in cultivating children's abilities to express human recognition as procedures with logical completeness. For example, only a few years old children can make a toy car follow a picture road. However, it requires a huge break-through to represent it on a computer program. To fill this gap, acquisition of mathematical and scientific concepts is apparently required. Development of an education model to make children acquire the ability to fill this gap is the most important purpose of our work.

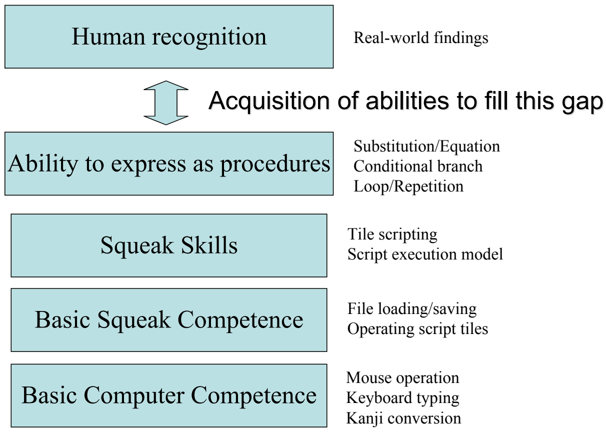

Figure 8: Learning Objective Hierarchy

3.2. Initial Experiment

First, we had a series of classes using the curricula such as "Driving a car curriculum" which had been already conducted in the United States as a prior experiment in 2002 and 2003 school year. In the 2002 school year, we held five SqueakToys workshops. In these workshops, the standard material that begins with the drive-a-car project was used because of our little experience and children made their projects freely in the last workshop. Some children made very interesting projects.

After these workshops, questionnaire surveys were sent out to teachers at two elementary schools and 25 teachers answered. Most of the teachers said SqueakToys would be useful (Table 2), especially to encourage the creativity and imagination of children. They thought SqueakToys would help teaching mathematics and science. This opinion is also said in one of the practice in United States. However, the majority of teachers answered that they would not use SqueakToys in the regular classes in the near term (Table 3).

Table 2: Answers to the Question:
How about using SqueakToys in education?

It will be useful.	16	64%
It will be not useful.	1	4%
Other	8	32%
Total	25	100%

Table 3: Answers to the Question:
Do you want to use SqueakToys in the regular classes?

I want to use it immediately	2	8%
If there is an opportunity, I want to use it in the regular classes.	13	52%
I don’t want to use in the regular classes but I will use in the extra classes.	4	16%
I have some interest but don’t want to use it.	4	16%
I don’t have any interest.	2	8%
Total	25	100%

One of the reasons of this hesitation towards the SqueakToys is that it sometimes doesn’t work well because of insufficient computer performance at these schools. Another reason, which was more essential, is the lack of enough support materials that are usable in the real classroom. This is the same issue of ineffective computer in real class.

Therefore, in the 2003 school year of the project, workshops were held as the extra classes after school through a year. Figure 9 shows the sights of these workshops. 19 children attend at Gosho Minami elementary school and 12 children attend at Takakura elementary school. We, staffs at Kyoto University, played a role as instructors, and we found it hard for only one teacher to conduct a workshop because children want to be taught immediately when they come up their idea but they can’t make it work it in Squeak. Some staffs always help the class.

Figure 9: Workshops as Extra Classes. One Teacher teaches to Children.
Some Staffs help the Class.

The questionnaire survey was conducted for fifth and sixth graders taking SqueakToys classes at Gosho Minami elementary school. Table 4 shows their statistical data. In the questionnaire, we asked their interest in computer, mathematics, science, and SqueakToys. The results of the questionnaire are shown in Figure 10 -Figure 13.

Table 4: Statistical Data

	Male	Female	Total
5th grade	57	61	118
6th grade	53	60	113
Total	110	121	231

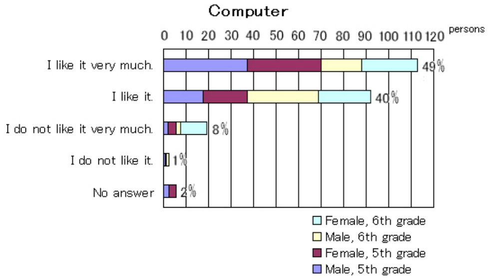

Figure 10: Rate of those who like Computer

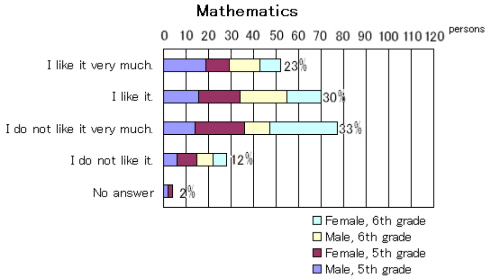

Figure 11: Rate of those who like Mathematics

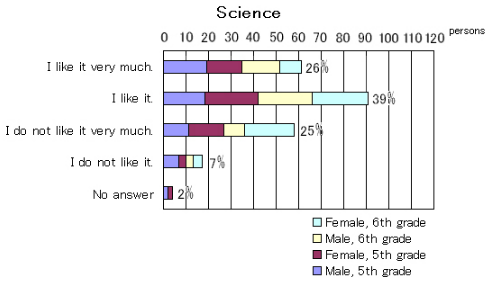

Figure 12: Rate of those who like Science

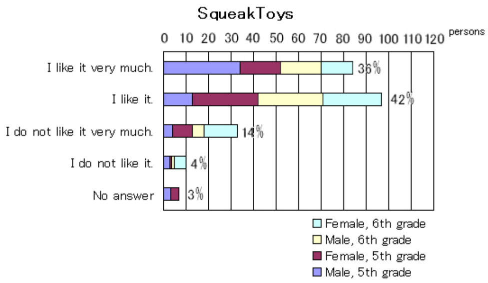

Figure 13: Rate of those who like SqueakToys

About 90% children like computers. However, there are not so many children who like mathematics and science. Thus, it is understood that quite a lot of children like computers compared with the subject like arithmetic and the science, etc. It is expected that children are interested and work on study by positively introducing the computer into the academic training, especially in the study thorough creation.

It is considered that one of the reasons why children do not like mathematics or science is that children think mathematics and science are examination subjects. The element of interest is important in the learning process through creation. From this viewpoint, a lot of children answered they liked SqueakToys despite the use in the class. Therefore, SqueakToys will be useful in the real class.

We interviewed teachers who looked at our classes. They thought children had a good time in the SqueakToys classes. However, they could not image the following two points.

- What could children learn?
- How would teachers teach?

The situation under children can program freely is not good for children to understand what they are studying. On the other hand, when the educational target is clarified, it can have risk that it is not different from an old cramming type study. Furthermore, teachers have anxiety since children sometimes try to make great projects they have difficulties to help. The reason why they have no confidence is that children can make what they like on programming, in addition to their lack of knowledge about computers.

These opinions are the same as the issues in the period for integrated study. It will be very critical issues to implement the SqueakToys curricula in real classes.

In addition, we explain the mathematical and science concepts to teachers which children will acquire. However, it is hard to understand these concepts since these concepts will often correspond to the national guidelines and state frameworks in the United States. It is important to develop curricula adapted for Japanese educational society.

3.3. The Definition of Curricula

In the previous section, the issues to conduct classes using SqueakToys were described. We propose that the curricula consist of the learning goals and the teaching materials. The learning goals show what children learn and the teaching materials help teachers. Taking in this definition, our educational model adapts to the period for integrated study [16].

- Learning Goals
  The learning goals consist of two parts.
  - Goals of Scripts to be made
    They show the concrete targets of a program.
  - Goals of Concepts to be leaned
    They show mathematical or scientific concepts.
- Teaching Materials
  Teaching materials include not only tools such as SqueakToys projects, textbooks and tutorials but also the management solutions like class plans.

In the class, teachers conduct classes with the following way reflecting the idea in Figure 2.

- Planning: Teachers show children what to make. (Children consider the goal of concepts.)
- Designing: Children consider how to make their project. (Children consider the goal of scripts.)
- Practicing: Children make their project.
- Evaluating: Children evaluate whether they achieve the learning goal.

It is expected that children learn mathematical concepts thorough constructing a SqueakToys project of their ideas in the designing and practicing part, and that they learn scientific concept through comparing their project and the real world in the planning and evaluating part (Figure 14). It is easy to observe the real world because they visualize their ideas.

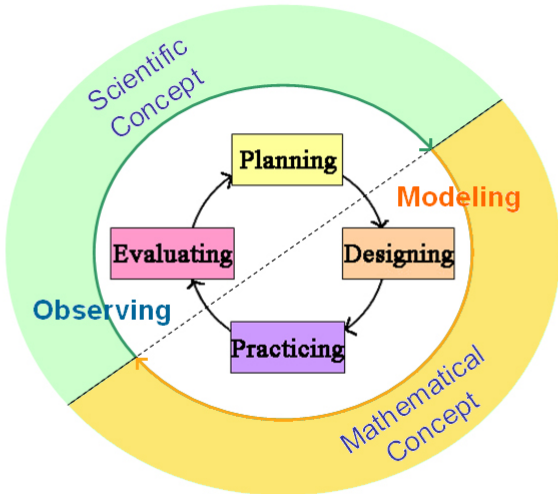

Figure 14: Acquired Concept through the Learning Process through Creation

3.4. Rubric

We use the “Rubric” in the way to measure learning effects and to evaluate curricula. The rubric is a table composed of concrete words that show various evaluation items and each attainment levels. It is said that the rubric improves the validity of the evaluation of the study activity of the process. Then the rubric can prevent from the ambiguity of the evaluation items. In our curricula, the learning goals are applied to the evaluation items.

Both teachers and children evaluate children and curricula with the rubric. Table 5 shows a related summary of the subjects and the objects.

Table 5: Related Summary of the Subjects and the Objects

	Children	Teacher
Children	Evaluation of the Understanding, etc. (self-evaluation & inter-evaluation)	Evaluation of the achieving the learning goals, etc.
Curriculum	Evaluation of the Degree of Difficulty, etc.	Evaluation of the Class Plan, etc.

The items corresponding to before, in and after class are set in the table. The ways to evaluate the items are not only the questionnaire or test but also the action logs recorded in computer.

Chapter 4 Practice

The issues of SqueakToys-based education at elementary school in Japan were turned out through the practice in 2003. With these issues in mind, we are developing Squeak-based curricula. In addition, various practices to develop SqueakToys-based curricula are going [17], [18]. Then the SqueakToys workshops are held after school at two elementary schools per two weeks through a year in order to verify our education model.

In this chapter, we will consider our model, taking the tadpole curriculum held at one of the schools for example.

4.1. Annual Plan

In the 2004 school year, we evaluated two curricula. The annual plan is shown in Table 6. A black box curriculum was first and the tadpole curriculum was second at Gosho Minami elementary school. On the other hand, Takakura elementary school followed the opposite in order to evaluate each curriculum twice.

Table 6: Annual Plan

	Gosho Minami	Takakura
First	Introduction	Introduction
Second	Black Box Curriculum	Tadpole Curriculum
Third		
Forth		
Fifth	Tadpole Curriculum	Black Box Curriculum
Sixth		
Seventh		

There are both the fifth grade and six grade children in the same class. Children taking the classes learned how to use SqueakToys in the previous year with the driving a car curriculum and so on. Each workshop takes one hour and a half. In these workshops, we took charge of a role of instructors.

4.2. "Tadpole Curriculum"

First the outline about the tadpole curriculum is explained. The aims of this curriculum are described below.

- Learning Goals

  Simulating the movement of tadpole on SqueakToys

  1. Shaking the tail
     - ✓ the observation of life and the realization of animation
  2. Moving randomly
     - ✓ the concepts of a random number and range
  3. Moving slowly when hungry
  4. The process that the tadpole grows up to the frog
     - ✓ the observation of life and the realization of conditional branching

As teaching materials, class planning, tutorial, rubric, and some sample programs are prepared. Table 7 shows a part of the class planning and Table 8 shows a part of the rubric for children. The text for children is prepared on the Web (Figure 15). This text describes the goal of scripts and hints of the way and if children attain the goal of scripts, they are requested to answer some questions related with the goal of concepts and the questionnaire about this curriculum.

Table 7: A Part of the Class Planning

Start	A teacher lets children write their images of tadpole in paper.
10 minutes	A teacher lets children pay attention to him/her. Then he/she lets them discuss their ideas. The following four points should be discussed. • Shaking the tail • Moving randomly • Food that a tadpole eats • The process that a tadpole grows up to the frog
20 minutes	A teacher shows a sample project. There are two tadpoles in this project. One moves around as if it is alive. However, another moves only straight. Then a teacher explains that one of difference is shaking a tail and he/she tells to children that they start to make a tadpole shaking a tail.
30 minutes	A teacher shows children the text on the Web. He/She let them write a tadpole which tail is straight.

Table 8: Part of Rubric for Children

Do you understand the random number?	Yes	Rather Yes	Rather No	No
Who do you talk when you have troubles?	Friends	Teachers	Friends and Teachers	No one

Figure 15: Example Text on the Web

4.3. Environment

The workshops with the tadpole curriculum were carried out as an after-school activity at Gosho Minami elementary schools in Kyoto. Table 9 shows their statistical data. Twenty three children who wanted to study by SqueakToys attended.

Table 9: Statistical Data of Children

	Male	Female	Total
5th grade	8	3	11
6th grade	5	7	12
Total	13	10	23

Three workshops were held and each workshop took one hour and a half. However, since a questionnaire was also performed within this time, substantial class hours were about an hour. In addition, the class has gone only to the goal of scripts, “Moving randomly” because of the lack of time. One of us behaved as a teacher and one personal computer was given to every child. Figure 16 shows the seating arrangement of children.

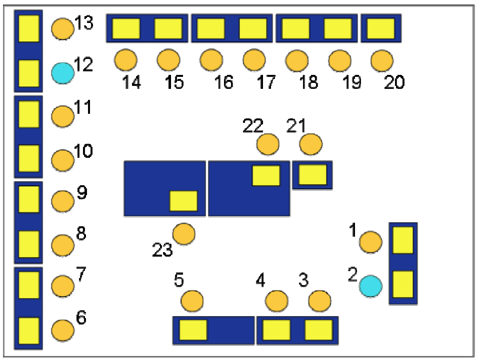

Figure 16: Seating Arrangement

4.4. Proceeding of the Workshops

Workshops proceeded in according to the following process.

- Planning Part
  We let children consider how tadpoles move and write their ideas in paper. Figure 17 is a sheet of paper written by one of children. Next, children discussed their ideas. Figure 18 shows a class scene in which one of the children explained a feature of a tadpole shaking the tail by his body. Then, we let children make a tadpole shaking its tail.
- Designing Part
  Children considered how to realize the tadpole in SqueakToys with referring to the text on Web or discussing with friends. We gave some hints to children especially who had little idea.
- Practicing Part
  After children understood how to make a project, they tried to implement it. Most of the children addressed the challenge by themselves.
- Evaluating Part
  Children can judge whether they can make a project through the result of execution or not. In the workshops, we made children submit their projects when they achieved every goal of scripts to be made. After submission, we showed the next goal.

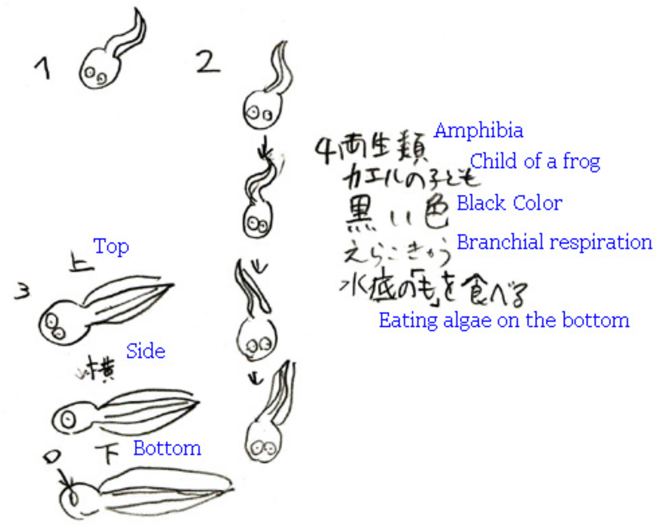

Figure 17: Sample of the Paper to which Child's Ideas are written

Figure 18: Class Scene

Figure 19 shows how children learn the mathematical and scientific concepts through this curriculum.

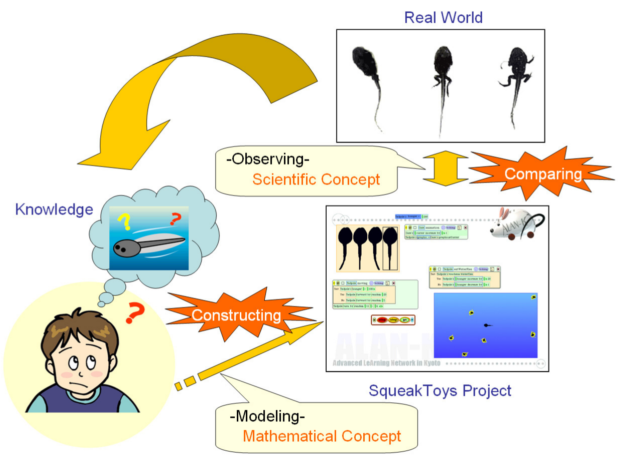

Figure 19: How to Learn the Mathematical and Scientific Concepts

4.5. Evaluation of the Tadpole Curriculum

In this session, we will evaluate what children learn through the tadpole curriculum and discuss to improve it.

4.5.1. Acquirement of Scientific Concepts

First, we discuss whether children have acquired scientific concepts.

In the tadpole curriculum, children cultivate the power of observation as the major scientific concepts. We consider that the power of observation means what to know and how to get the correct phenomenon. In the learning process through creation, children can develop their power of observation in mainly planning part and evaluating part. In this curriculum, it corresponds to planning part that children consider the ideas of a tadpole. Then it corresponds to evaluating part that children compare their projects and the phenomenon in the real world. Table 10 shows how children express their ideas of a tadpole and Table 11 is a list about their ideas of a tadpole. Most of them express their ideas by pictures.

Table 10: The Way of the Expression of Children's Ideas

Only Pictures	2	9%
Mainly Pictures and some Sentences	2	9%
Both Pictures and Sentences	13	56%
Mainly Sentences and some Pictures	5	22%
Only Sentences	1	4%

Table 11: Children's Ideas of a Tadpole
(Free description, Items are written by more than three children.)

	Picture	Picture and Sentence	Sentence	Total
How to Move	4	5	2	11
(Shaking a Tail)	(3)	(4)	(2)	(9)
Body Shape	7	8	0	15
Black Color	0	3	5	8
Child of a Frog	0	1	12	13
How to Grow	1	3	5	9
Where to Live	0	0	6	6
Born from Eggs	1	0	2	3

We consider that one of the evaluations whether children can get the power of observation is to measure the change in pictures, so first the results about change in picture are described.

When children describe something in pictures, children draw what they know, not what they see [19]. Kerschensteiner said there are four processes in developing to draw pictures [20]. First, children draw the object diagrammatically based on their idea. Second, they start to draw the object morphologically but some diagrammatical parts exist. Third, they draw the object correctly and the diagrammatical parts disappear. Last, children drew the plasticized object.

Therefore, they are categorized by three kinds of pictures: diagrammatic pictures like Figure 20, cartoon pictures which have big eyes or strange foot like Figure 21 and morphologic pictures like Figure 22. The rate of the Kinds of Pictures is shown in Figure 23. Most children drew a tadpole in their image.

Figure 20: Sample Diagrammatic Picture

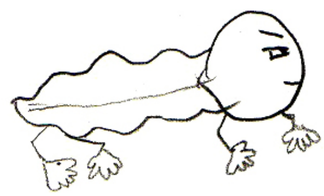

Figure 21: Sample Cartoon Picture

Figure 22: Sample Morphologic Picture

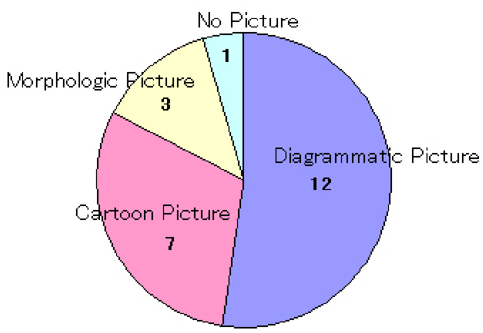

Figure 23: The rate of the Kinds of Pictures

Then the pictures drawn on SqueakToys are analyzed. Most children drew diagrammatic tadpoles like Figure 24. No one drew morphologic tadpoles.

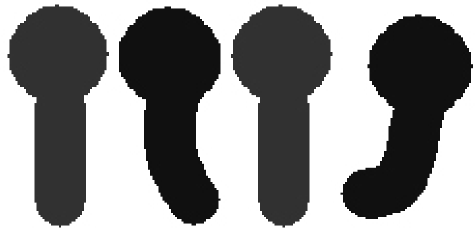

Figure 24: Sample Tadpole Made by Children on SqueakToys

In this manner, the change was not seen by children's pictures. Therefore, we cannot say that children acquired the power of observation from the view of change in pictures. The considered reasons are following points.

- It is difficult to draw pictures with the paint tools on SqueakToys.
- They did not have enough time to compare their picture and the real tadpole.
- Children are interested in motions of a tadpole rather than shapes when they make their project.

We focus attention on the last reason because the changes are seen in children's project. As a hypothesis, children can get the power of observation through the observation of motion in our SqueakToys-based educational model. Then we ask children whether they can make a tadpole as if it were alive. Figure 25 shows the result.

Figure 25: Result of the Question whether Children can make a Tadpole as if it was Alive

Most tadpoles made by children except the some children made in SqueakToys were the same but the result of the questionnaire is quite separate. Because of the difference of their thought, there is good chance to think the motion. In other words, children will get the power of observation of the motion in our SqueakToys-based education. Therefore, it is the motion that a teacher should let children pay attention to in the evaluating part.

From the view of this idea, we consider that it is appropriate that children make a tadpole shaking its tail in the first step.

4.5.2. Acquisition of Mathematical Concepts

Next, we discuss whether children have acquired the mathematical concept which is the goal of concepts of the tadpole curriculum. In the learning process through creation, children can learn the mathematical concept in mainly the designing part and practicing part. As the mathematical concept, the random number is taken for example.

The following questionnaire survey was conducted before and after the class.

- Before
    1. Do you know the random number? (Selection)
    2. If you know, please explain it. (Free description)
- After
    1. Do you understand the random number? (Selection)
    2. Please explain it. (Free description)

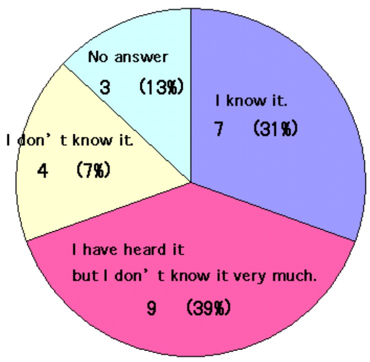

Figure 26: Question No.1 (Before)

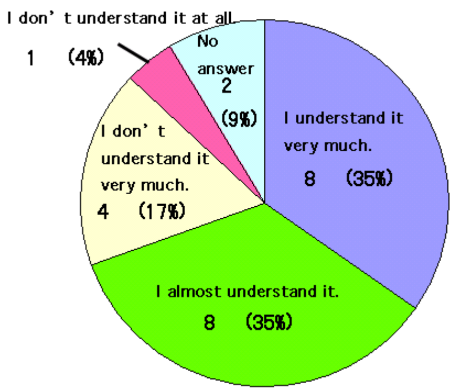

Figure 27: Question No.1 (After)

Figure 26 shows the result of the question No.1 for the questionnaire before the class was conducted. About 30 percent of the children knew about the random number. However, there were only four children who could explain it in the next question. The result of the questionnaire which asked whether children understood it after the class is shown in Figure 27. Since we explained the random number, it was taken for granted that children could answer that they understand it. However, it is more important how they understand the random number.

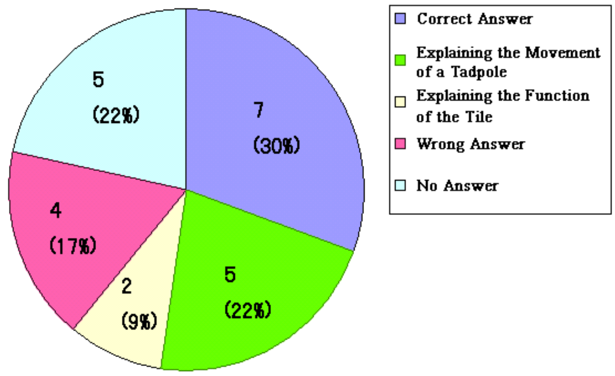

Figure 28: Question No.2 (After)

Figure 28 shows the result summarizing the free descriptions about the random number. Some answers are peculiar to the Squeak-based curricula. Five children explained it by the movement of a tadpole, like that a tadpole moves by changing speed. Two children explain the function of SqueakToys tile itself of the random number. This result says that about 30% children's answers were influenced by this curriculum. It is hard to say they could get the concept of the random number correctly. However, we consider that they can learn one of the cases using the random number.

In the Vygotsky's experiment, 90% children can understand a concept when they learn it in 4 or 5 different ways [21]. Then we develop other three curricula including the random number.

1. The Paper-Rock-Scissors Curriculum
   Children make the "Paper-Rock-Scissors" game with SqueakToys. The goal shown to children is to make the strongest "Paper-Rock-Scissors" mechanism. Because human thinking is not random, some rules will be effective to human beings. However, if the mechanism is completely random, every rule is not useful. In this process, children will get the concepts of the random number.
2. The Stopwatch Curriculum
   Children make a stopwatch. After making the stopwatch, children are let stop the stopwatch without thinking. The time is random in the result. Children will know they can make the random number by themselves.
3. The Sumo Curriculum
   Children make the "Sumo" which is Japanese traditional sports with SqueakToys. In this curriculum, random numbers are calculated mutually. Figure 29 shows the screenshot of the sumo project.

Therefore they are expected to get the concept when they learn it in different ways.

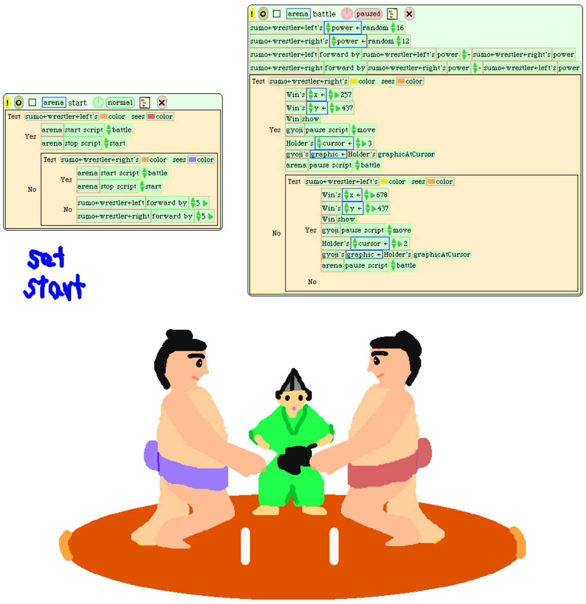

Figure 29: Sumo Project

4.6. Findings from the Practice

In this section, the findings from the practice are described.

The time of submission in the first class is shown in Figure 30. The vertical axis shows the children numbers which correspond to the seat numbers in Figure 16 and the horizontal axis shows the time of submission. The goal of the first step is drawing three appropriate tadpoles, each of which has a different direction of tails. Then the goal of the second step is making script of shaking the tail with basis of animation. At first view, the time of submission scatters very much despite the preparation of many teaching materials.

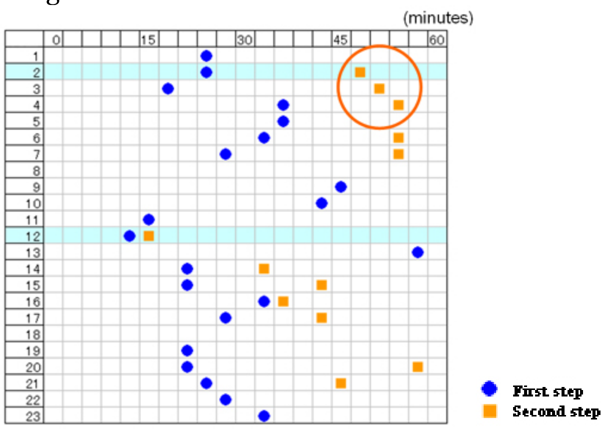

Figure 30: Time of Submission

We pay attention to two children, No. 2 and No. 12. They made interesting projects we have never considered in these workshops. The children who made the project which we have never considered are not in this class but also other class. Therefore we name these children the “high creators.” The definition of high creators is to be children whose idea of making scripts is different from the prepared one but it is correct. We explain the example in Figure 31 and Figure 32. The script of Figure 32 was made by No. 2.

Figure 31: Prepared Script

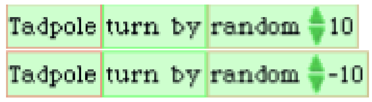

Figure 32: High Creator’s Script

The goal of scripts is to make a tadpole move randomly. A tadpole moves randomly in both scripts, so his answer is much comparable. However, the movement is different. With the script in Figure 31, a tadpole turns randomly in the range from -5 to 5 degrees in an equal probability. On the other hand, a tadpole turns in the range from -9 to 9 degrees in different probability with the script in Figure 32. It moves straight in 10% probability and turns in -9 degrees in 1% probability. Both expectation of degree is 0. It is considered that children will get the different mathematical concepts in each script. They will get the concept of range in Figure 31 and the concept of probability in Figure 32.

High creators sometimes come up with new ideas and implement these ideas. The project of Figure 33 was created by No. 12. The frog jumps in random interval of time and the tadpole escapes if the mouse is got close to it. He set his goal and realized his ideas.

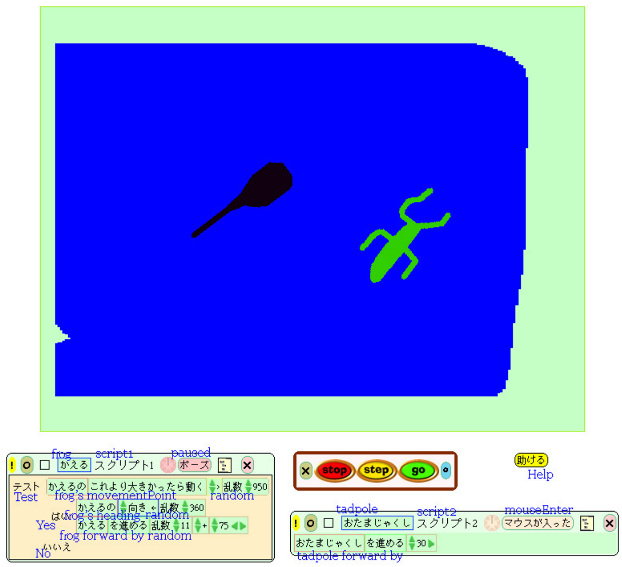

Figure 33: Project Created by No.12

Some features of high creators are found in Figure 30. No. 12 achieved the goals very early, so he made his own task and tried it in the rest time. On the other hand, No. 2 taught other children around him when he achieved his task. It reveals that the high creators played an important role in the classes.

This trend is found not only in this class but also in other classes. Therefore we find out that two kinds of high creator exist. One is a child who teaches one’s ideas to other children such as No. 2 and another is a child who just concentrates on one's work such as No. 12. We define a child who teaches one's ideas to other children as a leader-type high creator, and a child who just concentrates on one's work as a pursuer-type high creator.

Chapter 5 Improvement of Curricula with High Creators

In the previous chapter, we showed some educational effects and cleared up some important knowledge in our SqueakToys-based educational model. Then it is necessary to discuss what is needed in order to develop the SqueakToys-based educational model. In this chapter, first, the necessity of improvement in curricula is described. Then we suggest the way to improve curricula with activity and project of high creators.

5.1. Necessity of Improvement of Curricula

The definition of an ideal education is a problem under debate. The ideal education we think is to understand what all children should enjoy and to give them the chance to enjoy advanced learning. SqueakToys gives children the chance to think everything. However, the advantage can be a fault because if children make projects freely, teachers cannot control the class. It means not all children have opportunities to study. Therefore when we consider the development of the educational model in real classes, we should pay attention to teachers.

In order to solve this issue, the following points are considered.

- Improvement of teacher's knowledge
- Enrichment of the supporting environment for teachers
  - ✧ Support by human being
  - ✧ Enrichment of materials
  - ✧ Support by information technology

Thinking about these points, it spends little money and time as possible. In Japanese elementary school, teachers should teach all subjects. Therefore, they have widespread knowledge but most teachers do not have exclusive knowledge. In addition, they are so busy that they have little time to study new things. From this reason, it is difficult to improve teacher's knowledge deeply. In addition, it is difficult to prepare the supporting environment by human being because of the problem of money and so on. Therefore we select the way to enrich materials and to support teachers by information technology, that is, to improve the curricula.

High creators give a great idea to the curricula and have a profound influence on other children in the class. Then we suggest that it will be effective to analyze their activity and project in order to improve the curricula.

5.2. Maturation of Curricula with High Creators

First, we define the maturation of curricula. We consider that teachers can control the class with the curricula which is mature. High creators give a lot of instructive knowledge but their existence can be the reason why teachers cannot control the class.

If the ideas of high creators are taken to a curriculum after a class, it can be said that the curriculum is more mature. By repeating this process, the number of high creators will reduce. Therefore when the little new ideas arise even if classes in the curriculum are taken at some times, the curriculum becomes mature. In a mature curriculum, teachers come to control the children's creative activities, and they can help children who suffer from the recollection of the idea. Figure 34 shows this idea. This idea is seen from the teacher's view.

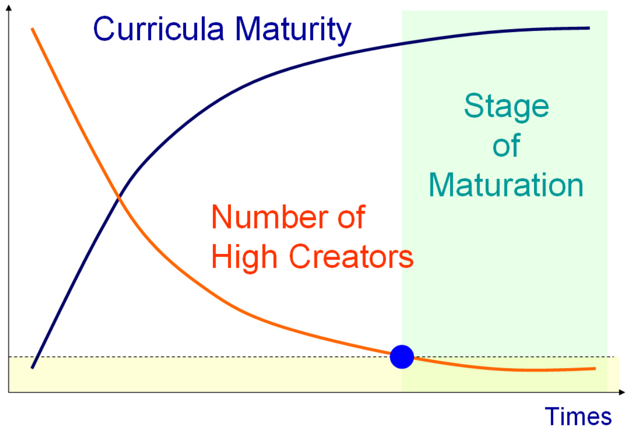

Figure 34: Maturation of Curricula from the Teacher's View

On the other hand, from the children's view, children can get ideas of the past high creators in a mature curriculum. Therefore, it is considered that it is possible for every child who takes a class in the maturity level of the curriculum to reach at the level of high creators ideas who take a class in the early curriculum. This idea is shown in Figure 35.

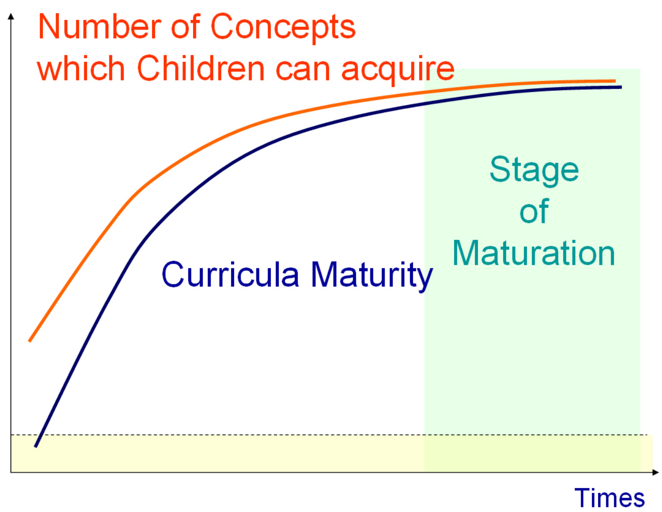

Figure 35: Maturation of Curricula from the Children's View

5.3. Primary Ideas in Mature Curricula

In the previous section, we defined mature curricula. However, every idea in mature curricula cannot be taught in the class because of the lack of time. Then we consider that it is necessary to apply priority what teacher should teach to all children.

We described two kinds of existing high creators in section 4.6. It is easier to understand how ideas of leader-type high creators influence other children than pursuer-type high creators. Therefore we pay attention to leader-type high creators to solve this problem. The degree of the influence on other children can be measured from time of submission like Figure 30, seeing their project, observing the class environment and so on. With the information, priority of ideas will be decided. For example, it will enable to decide the priority to measure how many children who take in ideas of leader-type high creators are.

On the other hand, pursuer-type high creator will tend to make difficult projects that teachers cannot help with ease. Then if pursuer-type high creators ask their question to a teacher, teachers will have to spend time to the pursuer-type high creators. Therefore, reservoir of ideas of the past pursuer-type high creators is important and the mechanism which support both teachers and pursuer-type high creators support is necessary.

Table 12 shows the difference between leader-type and pursuer-type high creators.

Table 12: Difference between Leader-type and Pursuer-type

	Leader-type	Pursuer-type
Influence on Other Children	Large	Small
Complexity of Scripts	Inverse Proportion to the Number of Children Leader-type influent	Proportion to the Working Time
Difficulty to help	Small	Large
Priority of Ideas to teach All Children	Proportion to the Number of Children Leader-type influent	Teacher's Judgment

This way will greatly lead to the establishment of a SqueakToys-based educational model aiming for the acquirement of mathematical and scientific concepts.

Chapter 6 Conclusion

This thesis has described a SqueakToys-based educational model at Japanese elementary schools. The contributions in this thesis are the following points.

- Design of the SqueakToys-based educational model taking in the learning process through creation
- Analysis of problems in the SqueakToys-based education through the practice
- Measurement and evaluation of learning effects about mathematical and scientific concepts
- Discovery of high creators who play a role in the SqueakToys-based educational model
- Suggestion for ways to improve curricula with high creators

We consider investigation of high creators to be our largest contribution. We insist that our contribution will be useful under the situation in the different progress of the class.

As future work, we should consider a systematic way to utilize high creator's feedbacks to improve the curricula. We should also take a long time to evaluate our educational model.

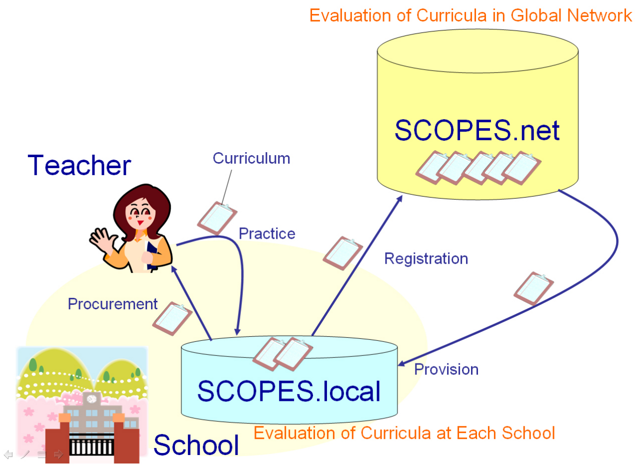

Figure 36: SCOPES

In addition, it is important to share good curricula in order to enjoy a good education for all children. Therefore, we are also planning to design and develop systems called SCOPES (Sharing Curricula Over Practice-based Evaluation Systems) [22]. Figure 36 shows the SCOPES.

Education is the basis of society. Especially, children should create a bright future. In this research, we designed a new educational model. We believe it would be a contribution to social informatics.

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