A Research on Creativity in STEM Integrated Learning Environment Based on Task Specific Approach

A Research on Creativity in STEM Integrated Learning Environment Based on Task Specific Approach

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF
THE SHIZUOKA UNIVERSITY
BY

Tomoki Saito

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Yoshisuke Kumano, Adviser
Yugo Takeuchi, Co-adviser
Jun Oshima, Co-adviser
Yasuhisa Oya, Co-adviser

December 2016

Acknowledgments

I owe my deepest gratitude to my adviser, Dr. Kumano, Dr. Takeuchi, Dr. Oshima, and Dr. Oya. Also my mentor in University of Minnesota STEM Education Center, Gillian Roehrig Ph. D. gave me the wonderful opportunities for constructing this dissertation. Also the colleagues in the center cheered up a lot and contributed to this research; Dr. Fred Finley, Dr. Thomas Meagher, Dr. Hui-Hui Wang, Dr. Julie Brown, Dr. David Kimori, Dr. Forster Ntow, Dr. Deverati Bhattacharya, Dr. Emily Dare, and Dr. Josha Ellis.

In addition, I am grateful the graduate students and undergraduate students who contribute to this study, H. Ishikawa, M. Kobayashi, K. Maeda, Y. Matsushita, and H. Sasaki.

Dedication

This dissertation is dedicated to my parents, grandparents, and researchers who affected on me.

Abstract

This study aimed to solve these four research questions. (1) How task specific approaches improve students' creativity in the extent of Torrance Tests of Creative Thinking (TTCT) that was applied to the area of integrative Science Educations or its STS approaches? (2) Are the students' creativity assessed differently in each area of STEM? (3) When students engage in the STEM independent practices, how do they follow the cascades of eight practices? Are they different in each group? (4) What kinds of potential creative tasks do students show during their own cascade of inquiries (practices)? (5) If students realize the task specific divergent thinking, where & when do they apply it to their own inquiries (practices)?

To resolve those research questions above, the author employed mixed methods approach and utilized both quantitative and qualitative analyses. First, to answer to the questions (1) & (2), TTCT and Consensual Assessment Technique (CAT) were used and analyzed statistically on paired t-test as the quasi-experimental approach, and zero order correlations. In addition, to answer to the questions (4) & (5), both qualitative and quantitative approaches were used. For question (3), the author made cascade graph tentatively, the difference of cascades were confirmed.

Those data were taken on the participants of the Future Scientists Program called Shizuoka STEM Junior Project who were 5th through 9th grades students. In the program, the participants engaged in the group inquiries (practices) and tried to develop their own questions/problems, and to solve it by themselves. The educators kept their attitudes as a coach and intervened in participants' inquiries as less as possible. The participants recorded their reflections just after the each day practices. The reflections included where they used their creative/critical thinking, where they applied it their own inquiries (practices), and what practices they were going to do in the next time. The TTCT and CAT were done on the first and last time of the program.

From the results of TTCT, on the question (1), the participants' creativities were improved significantly on the fluency, and uniqueness. Two master students and three undergraduate students evaluated the pre- & post-

tests. The inter-rater reliabilities were checked on coefficient α (pre: .80- .84; post: .43- .76). The paired t-test between pre and post-test showed the creativity in fluency and uniqueness were improved (two tailed; **p<.01; *p<.05, t value= -5.50 - -1.30, effect size= .81 - 1.52, and power (1-β err) > .90). However, the uniqueness of possible causes task and fluency and uniqueness of predicted consequences task were not improved (two tailed; *p<.05, effect size= .35 - .74, and power (1-β err) < .90).

On the other hand, the CAT showed, as predicted, the experts' assessments on the participants' products were different each other from the result of the calculation of coefficient α and the zero order correlations. Although this result does not depend on enough number of judges for some of those domains, the judges assessed differently even in the science domains. Thus, as Bear (1993) suggested the divergent thinking is not a single creativity factor throughout any domains and the "domain specific"; furthermore "task specific" approaches are needed.

However, the STEM educators did not have any frameworks to identify the creative tasks that were used in the STEM independent inquiries (practices), even if the process skills, sequences, or heuristics of (creative) problem solving had been suggested. Rather cascade of practices (Chin & Brown, 2000; Chin & Osborn, 2007; Pratt, 2013) should be examined. Thereby, the author tried to describe a case of students' cascade on STEM practices by explanatory qualitative approaches.

As the result of the explanatory approach, which answers the (3) question, the students' cascades of STEM practices were not necessarily follow the eight practices 1 to 8 as Pratt (2013) suggested, and back and force on their own cascades. Thus, when the author examined the differences among students within those groups, they had different cascades among the members of each groups. In addition, from the result of coding of students descriptions on when and how they used the creative thinking in their own inquiries, the descriptions almost took place in the phase of eight practices whose were possible creative tasks in STEM independent inquiries (practices). However, those tasks were more concrete and should not be described as STEM general tasks to be

explained; rather it should be elaborated and be viewed for teachers to support the students' creative thinking in their own cascades of practices.

In conclusion, by resolving four research questions, the author found that the participants' independent inquiries (practices) in a STEM Integrated Learning Environment supported the improvement of their creativities, but the experts in the different STEM domains assessed them differently. Furthermore, the participants' own STEM inquiries (practices) followed differently in the cascades of eight practices. Therefore, the tasks, which the author found from the students reflections, would be the candidates of application to the creative problem solving in the STEM learning.

Table of Contents

List of Tables

List of Figures

Chapter I Introduction

Rationale

Rationale for this study came from the historical background for science education.

STEM education has been a big educational topic all over the world (Kumano, 2012). Although the learning across the disciplines has been suggested in the history of science education (DeBoer, 2006), the specific frameworks for assessment beyond the disciplines was not stated yet (Saito, Anwari, Mutakinati, Suwarma, Shido, Kumano, in press). Similarly, 21st century skills were advocated (Koenig, 2011; Stuart & Dahm, 1999) which were based on the understanding of skills needed for the changing economies. However, the specific characteristics of those skills did not apply to the total perspective of the "generic" 21st century skills for their construct. For example, the fact that some of the 21st century skills have been suggested that they had domain specific characteristics (domain specificity: Koenig, 2011; Bear, 1993) has not risen up on the discussions among such "generic" skills. In such situations, as STEM education reform aims to teach innovation and entrepreneurship (National Science and Technology Council: NSTC, 2011), creativity and some of the 21st century skills, must be improved in STEM Education. Moreover, it should be examined on those characteristics that transferability and domain specificity.

The integrative approaches also have advocated in the STEM Education fields (Laboy-Rush, 2011; Sanders, 2009). Sometimes, it has taken as interdisciplinary approaches between two or more STEM disciplines (Bybee, 2013) and sometimes it has taken as transdisciplinary approaches (Vasquez, Sneider, & Comer, 2013). The author and the colleagues have taken the transdisciplinary approaches in their STEM project and it has aimed to develop theories for Japanese STEM approaches. The project also aimed to find and overcome the problems on such integrative approaches and to implement them in the informal and school settings in future. (Saito & Kumano, 2015abcd; Saito, Gunji, & Kumano, 2015; Saito, Anwari, Mutakinati, & Kumano, 2016). As the result, the theories and tools for developing and implementing integrative STEM classes have been built. On the other hand, some 21st century skills have domain specificity and their application to the integrative STEM classes need to be considered. A number of studies or reports discussed or recommended the 21st century skills and their application on STEM education (Laboy-Rush, 2011; Vasquez, Sneider, & Comer, 2013) and they usually used Project-based Learning as their environment. Actually, their results showed the improvement of 21st century skills. However, the difference of the skills and their assessment in each domain or applications to each task of students had not discussed. Indeed, the implementations were specific, but the assessment sometimes took "generic" approaches. The misconnections between the theories and implementations should be considered.

Therefore, this study needed because the domain specificity of creativity in the integrative STEM classes (particularly in the trans-disciplinary approach) needed to be confirmed and discussed with its application into concrete implementations in PBL.

Statement of the Problem

Background of the Problem

Student-centered integrative approaches which grounded by the constructivism (Vyhmeister 2001; Mattes 2008; Nakamura, 2007) had not meant that teachers have not taught anything (NRC, 2000). However, it has been recommended to do independent inquiry (NRC, 2005) and emphasized the real-world context in the educational researches (Fensham, 2009).

Although, in many contexts, it had been discussed about nurturing scientific literacy and been assessed for the competences to solve "unfamiliar problem" (PISA, 2012), the literacy in the school setting still has meant that "knowledge that teachable": as we have called discipline (Phenix, 1962) and teachers still have been focusing on the achievement (Yager, 1986, 2014; Saito et al, 2016). Unfortunately, it has not been equal to the characteristics of literacy that solving the socio-scientific issues (DeBoer, 2006; Hurd, 1958).

Statement of the Problem

Thus, the problem here that we do not know what we are going to teach. Because the things "what students become able to do, in the real-world context" were not the contents (substance) nor the abilities (syntax) belong to the discipline where teachers had studied which the Course of Study in science (MEXT, 2008) has been stated, but the one which has existed beyond the disciplines and been called 21st Century Skills (Koening, 2011).

However, if we are able to reveal the characteristics of those 21st century skills, it is possible to suggest "what we are going to teach" and "how students learn" in the student-centered integrative approaches such as Project-based Learning and/or Active Learning as the forms of STEM Education (Saito, Kumano, 2016).

In such situation, things what we need to do are suggesting some specific models which can conserve the student-centered learning environment and describe how teachers can support their learning for the 21^{st} Century skills (Saito, Anwari, Mutakinati, & Kumano, 2016).

Theoretical Framework

In this study, the author relies on both pragmatism and radical-constructivism. Because, as educational research, this study considers the coincidence of research and practices, and conducted Design-based Research.

As the research part, the author relies on pragmatism and employed mixed methods approach (see methodology). As the theoretical framework, pragmatism was advocated by Pierce (1931), James (1907) and Dewey (1938) those who brought it into education. In their mind, pragmatism had the ground on an epistemology that "fallibilism" (Dewey, 1938; James, 1907; Pierce, 1931). In this notion, the knowledges are not perpetual and because of its uncertainty and indeterminacy, the solutions may exist in several shapes (James, 1907). This understanding is very similar to the idea of design or engineering and it is suitable for the studies of Design-based Research (Barab & Squire, 2004). Actually, the Design-based research is not a fixed method, but a collection of approaches (Barab, 2014). Thus, in this study, the author takes it as the part of theoretical framework rather than the methodology.

On the other hand, the author adopted radical-constructivism as the practical side of the theoretical framework. Glasersfeld (1995) had claimed radical-constructivism that also had characteristics of fallibilism (Ernest, 1991, 1995). His idea aims to support practices by those theories of constructivism. To construct the implementation, the fallibilism appears as naturalistic approach (Appleton & King, 1997), and it is a basis of design-based research.

As Glasersfeld (1995) stated, the author believes theories become the powerful tool for implementations and thus the implementation can generate next theories as their basis. Therefore, as Dewey (1938) mentioned, theories become the instrument of the implementations.

Goals and Objectives

Purpose of This Study

This study confirms the domain specificity of creativities (Bear, 1991) among STEM area, and tries to identify the students' narratives to apply task specific divergent thinking to their own inquiry with align to the heuristics supported by the eight practices in Next Generation Science Standards (2013). The Research Questions that guide this study are follows:

(1) How task specific approaches improve students' creativity in the extent of Torrance Tests of Creative Thinking that was applied to the area of integrative Science Educations or its STS approaches?
(2) Are the students' creativity assessed differently in each area of STEM?
(3) If students engage in the STEM independent practices, how do they follow the cascades of eight practices? Do they difference within/among groups?
(4) What kinds of potential tasks do students show during their own cascade of inquiries (practices)?
(5) If students realize the task specific divergent thinking, how do they apply it to their own inquiries (practices)?

Research Hypothesis

The research hypotheses for this research stated:

(1) Task specific approach in independent STEM practices will improve students' creativity in the extent of Torrance Test of Creative Thinking.

(2) Even if the students' creativity improved in the extent of Torrance Test of Creative Thinking, the experts in different domains of science would assess their product as a scientists and/or an engineer differently.

(3) While students have different narratives of inquiry, they will follow the different cascades of STEM practices.

(4) As they freely apply the divergent thinking to their own STEM practices, they apply it to different times and phases of their inquiry.

Significance of the Study

If this study would be completed, the characteristics of creativity in the context of science and STEM education will be clarified. Especially on the application of divergent thinking will get its basis. Because, the moments and context for applying the divergent thinking skills were not identified in this domains and the possibilities in the integrative learning environment have not been discussed.

Although it had introduced such integrative approaches and the importance of student-centered approaches, the implementations usually had difficulties because specific characteristics of learning environment had not been tested in the real educational context. Similarly, on the creativities, the focused program on CPS and its task specific approaches had not tested in the Japanese context.

Therefore, for the development of 21st century skills and the education, this study should be completed with such significance.

Definition of Terms

Argumentative Grammar
The descriptions of the method, which were adapted to the practical education researches, based their theoretical framework on Action Research or Design-based Research.

Cascade
Generative activities (practices) which are led by the questions (Chin & Osborn, 2007) and they are unfolding and often overlapping (Pratt, 2013).

CAT (Consensual Assessment Technique)
The CAT is an evaluation tool used by creativity researchers for assessment of creative products by panels of raters. The method assumes that "a panel of independent raters familiar with the product domain, persons who have not had the opportunity to confer with one another and who have not been trained by the researcher" are the best able to make judgments regarding "the nature of creative products and the conditions that facilitate the creation of those products" (Hennessey, Amabile, & Mueller, 2011, p, 253).

Creativity
Very personal whole structure of knowledge and technique to create (Bailey, 1969); A product or response which appropriate observers independently agree it is creative (Amabile, 1982).

CPS (Creative Problem Solving)
Process invented by Osborn where you alternate divergent production and convergent production (Piirto, 2011).

Divergent Thinking
The revised meaning of divergent thinking does not only mean the skill as the whole, but also mean the thinking skills applied to the specific tasks and one of the creative thinking skills.

Heuristics
A nonrigorous method that is achieving solutions of the problem (Bruner, 1961).

Practices

Scientific practices aim at proficiency, learning subjects thoroughly at school, and applying knowledge for an objective (Bybee, 2011) and are connecting each other as cascade.

STEM

The acronym for Science, Technology, Engineering, and Mathematics (Bybee, 2013).

STEM Education

Education in the subjects of science, technology, engineering, and mathematics, including computer science" at federal agencies which funded by NSF (House of Representative, 2015).

Summary and Overview of the Following Chapter

In chapter II, the author arranges related theories on the literatures and makes specification of the way to define the research questions and hypothesis of this study. The topics are STEM Integration, Contested History in Science Education, Creative Problem Solving (CPS) as heuristics for real-world problem solvers, the Characteristics of CPS, and Task Specific approach for STEM Inquiries (Practices). In chapter III, the author provides the details of research design, methodology, and methods employed for this study. Chapter III includes such sections as (a) Methodology: why mixed method approach is appropriate for this study; (b) Methods: details to conduct this study; (c) Assumptions and Limitation of This Study. Chapter IV arranges the result and discussions on the quantitative part of the study. Result 1 shows the result of Torrance test of creative thinking. Result 2 shows the result of consensual assessment technique. Result 3 shows the correlations among the participants' cascades of inquiries (practices). In Chapter V, the result of qualitative analyses will be shown. As the qualitative part of this mixed methods approach, the author analyzed the participants' reflections on the application of creative thinking on to their group inquiries (practices) and their own independent inquiries (practices). In Chapter V, the result of qualitative analyses will be shown. As the qualitative part of this mixed methods approach, the author analyzed the participants' reflections on the application of creative thinking on to their group inquiries (practices) and their own independent inquiries (practices). The last chapter VI arranges the discussions from the data of mixed methods analyses and provides meaningful discussion for the further researches.

Chapter II: Review of the Literature

This chapter II arranges related theories on the literatures and makes specification of the way to define the research questions and hypothesis of this study. First, the discussions among STEM integration show how and why this study prepared such learning environment. This understanding supports the design conjectures of the learning environment for this study. Second, the transfer issues that applied to the creativities are discussed. The misconnections between learning environment and the domain specificities state the research questions and the theoretical conjectures for this study (see Chap III for the explanations of those design & theoretical conjectures).

The Basis of the Design for STEM Integration

For the very first section of the literature review for this study, the author explains why the STEM Integration is needed and what are the challenges should be overcome in this era of STEM education. The discussions suggest the design of the learning environment for this study.

Categorized STEM Education

There are numerous discussions about what STEM education is. Someone says that it is not a research theme, but just a political action (Bybee, 2013). Another one believes that we seriously need to consider the STEM education as a research topic and try to define what the STEM education is (Sanders, 2009). However, STEM education is obviously advocated by federal government and the definition is not focused on what the contents they taught or how they should be taught, rather federal advocacies themselves are trying to define effective STEM education (President's Council of Advisors on Science and Technology, 2010).

Among those federal advocacies, STEM Education Act of 2015 defines STEM education as ”education in the subjects of science, technology, engineering, and mathematics, including computer science” at federal agencies and states the three categories which would be funded from NSF (House of Representative, 2015). Those categories are single STEM discipline, multiple STEM disciplines, and integrative STEM initiatives and may encompass any STEM initiatives in-school and out-of-school settings, although this STEM Education Act of 2015 focused on informal (out-of-school) settings.

This categorization by the STEM Education Act of 2015 is very similar to the one that had stated by Fogarty (1991) about the integrative approaches in 1990s. Fogarty indicated ten methods of curriculum integration that were *Fragmented, Connected, Nested, Sequenced, Shared, Webbed, Threaded, Integrated, Immersed,* and *Networked.* The characteristics of those are examined in Saito Anwari, Mutakinati, and Kumano (2016) with STEM education.

He classified these methods into three categories: Within Single Disciplines, Across Several Disciplines, and Within and Across Network of Learners. These classifications imply where S/T/E/M learning will be integrated. First, where learning is integrated within single disciplines, integration can appear in traditional classes that discretely separate subjects. Second, if STEM learning is integrated across several disciplines, it might lead to teachers' cooperation or subjects' reconstruction; hence, integration should occur in teachers' meetings or curriculum development. The third classification seems a better fit with the student-centered notion; integrated within and across network of learners, integration would occur in students' learning, in their communities, or in their brains (Saito et al., 2016).

Based on this understanding, in this study, the author focused on the STEM integration within and/or across network of learners as an environment for the student-centered approach like in the Fogarty's classification and called it as STEM Integrated Learning Environment (SILE; Saito et al., 2016).

Why Integrations Are Needed in STEM?

The reasons why such integrative approaches in SILE are needed are their way to provide student-centered learning environment, its relevance on students' real world, and the construction of relationships among STEM area of learning.

Related articles in STEM education are discussing that one of the reason why students need integrative learning is to provide real-world context (Bybee, 2011, 2013; Fensham, 2009; Katehi, Pearson, Feder, 2009; PCAST, 2010, 2012), and to elicit their interests and identity. The learning only comes when what is learned is relevant to the students' life experiences. This may be why so many students have difficulty remembering what is taught in schools (Clark, 2005). Thus, by using real-world context, SILE should provide more students-centered learning experiences (Saito et al., 2016). Furthermore, STEM education also aims to connect their future carrier and to help provide students with skills they will need as workers and citizens (Olson, Labov, 2014; PCAST, 2010, 2012)

Many of experiences in the development of STEM education in an integrative way have shown the obstacles to be overcome. However, when it had been attempted, the integrative approaches have stimulated students' energies because it gave meaning and relevance to the scientific content and process of their learning (D'Ambrosio, Black, El-Tom, Matthews, Nebres, & Nemetz, 1992).

These claims were very similar to the STS approaches (Saito, et al., 2016) in 1990s and came from the view that variety of conceptual relationships among STEM subjects and the fact that scientific inquiry and the engineering design activities provide more concrete and relative learning each other (Beatty, 2011).

Contested History in Education

Although the integrative approaches claim that they support student-centered learning (D'Ambrosio, 1992; Fensham, 2009) and the activities can provide real-world practical experiences (Clark, 2005), the traditional teaching and practical education have been a contested position in the education history (DeBoer, 2006). Sometimes, it was the argument between project methods (Dewey, 1938; Kilpatrick, 1931) and traditional lectures, and the integrative approaches had been discussed both in Japan and the US. Sometimes it was a challenge by the core-curriculum movement and it was transfer to the Japanese education system. Then, they led the development of geography and social studies. Actually, the teachers of social studies usually taught the core-curriculums (National Society for the Study of Education, 1947). Also in 1950s and 1970s, the integrative approaches were discussed in Japanese context and it was a discussion led to the "Time for integrated learning (Ministry of Education Culture Sports Science and Technology, 2008)". However, the conclusion at that time was "the integrative issue expected to be dealt on out-of-subjects in the curriculum" (Umene, 1977)

In the following part of this section, the author arranges the discussions from those histories and suggests what the challenges in current STEM education movement and its implementations that would be overcome in this study.

Before the Idea of Integration

In the pages of "Yale Report" (1828), there was a sentence that "classic" educators reply to the "new" practical education that science. The ideas are not directly related to the integration issue, but to the idea of discipline an important topic in this section.

In their notion, the classic education did not only develop the sense of correct, the basis of the ideas in resent literatures, and abilities to get them from the original sources as they are, but the learning itself construct the discipline as the mental abilities. The "old" sentences have advantage because the set of disciplines afford the best for the mental cultures and lead the perfect knowledge in our literature, and build the foundations for our specialized work, they wrote (Yale corporation, 1828/1961, pp289-290; in DeBoer, 1991). The advocacy of practical educators answered, on the other hand, that science provided the most appropriate mental discipline (DeBoer, 1991).

The discipline in this era meant the refrain of teachers' dictation and the mental discipline imprinted as the "memories." Although it was a point whether what they called discipline was the same as in 1960s, it would not be discussed here. However, the term discipline would be discussed later in this chapter. Because, the discipline was an axis of the contested history.

The Starting Point of Integration

From the late 19th Century and in the first few decades of 20th century, Dewey discussed the integrative approaches and/or project method that called by Kilpatrick (1918) later. At the same year of when Dewey published "School and the Society" (1899), Higuchi (1899) also discussed "integrative instruction" in this era (Shono, 2014). The integrative approaches yielded in both Japan and the US.

Those approaches have effected to a number of educational activities. However, those approaches also met the critiques. Umene (1977) had arranged possible critiques from the realistic view and they should be overcome in the approaches, which aim the student-centered approaches (Saito & Kumano, 2016).

- If schools do not teach anything, as they call it as autonomy of students' learning, students learn from their parents and work hard to complete the assignments.
- To elicit students' spontaneous learning, the class must be a project and students resolve the possible problem that is necessarily to complete their work.
- Thus, the curriculum cannot be the parallel subject style (Umene, 1977, pp.89-91).
- On the other hand, the more educators respect the students' life and students pursue what they want, the more class become instantaneous.
- The class becomes less responsible and insufficient on the perspective of the role of teachers for the future society (pp.91-92).

The discussion by Umene (1977) was similar to the critiques by Hutchins or Adler. However, according their opinions were to the follower of Dewey called "progressive movement" and both Hutchins and Adler valued Dewey's theoretical insight later (e.g. Adler, 1941/1990; 1984).

> I had in mind the fundamental soundness of the project method (though I abhor the name), the method which stresses activity on the part of the learner as indispensable, which emphasizes the great importance of understanding the problem before knowing the answers, which places the acquirement of skills before the mastery of subject matters in the domain of basic general education (Adler, 1941/1990).

The point, as Adler stated, contents (substance) or method (syntax) also was the topic of the discussion as the focus of the discipline.

Discussions Related to the Project-based Learning (PBL)

About these project type of education, Kain (2003) had discussed the differences of Project- and Problem- based learning. In his notion, the difference was based on the focus. For example in the project-based learning, the learning process focused on the outcome (product), although the projects of students are different each other. On the other hand, problem-based learning focuses on its process of inquiries. In this sense, the problem-based learning does not focus on the outcome. However, both of them using "real-life problem" as the part of their instruments.

Although students are able to achieve the content knowledge the same or more than traditional lesson in PBL (Kaufman & Mann, 1999; Richard & Dods, 1997; Thomas, 2000), focusing on the outcome is needed to develop their competences (see also characteristics of CPS later). If we look at the creativities as the competences to develop creative outcome (Bailey, 1979), the PBL become a learning environment that produces the outcome.

STEM PBL usually set the outcome as engineering solution and set the environment as project(s) to solve the engineering problem(s) (Han, R. Capraro and M. Capraro, 2014; Moore, Glancy, Tank, Kersten, Smith, & Stohlmann, 2014; Roehrig, Moore, Wang, & Park, 2012). However, here has been a question that "who decide the engineering problem" (Vasquez, Sneider, & Comer, 2013) and the author had been discussed on this point (Saito & Kumano, 2015a). In the STEM Classes at the Shizuoka STEM Junior Project 2014, the engineering problem for each lesson had not decided, but just predicted by the teacher prior to the lessons. If we take it as student-centered notion, the engineering problem can be decided with the students (Polya, 1965; Vasquez et al., 2013). However, there are many critiques on such student-based decision onto the problems, which would be dealt with in the project-based classes (Ando, 2007; Matsu-ura, 1987). Kain (2003) also discussed on this point that "*selection and connecting the good problem*" and suggested that the good problem can be stimulate students. However, is the problem finding itself not a part of learning? (Runco, 1994)

Actually, many of studies which discussing problem solving (see also the section discusses problem solving approaches below) and those lists of sequences include questioning or defining problem part at the first phases. However, many of implementations did not ask students about their own questions (Watanabe, 2010).

On the other hand, the researchers who advocate PBL or active learning had taken emphasis on the students' role to decide the questions. For example, Polya (1965) suggested the effect of active engagement of the students to decide the problem, which will be solved later. He assumed that if students share the responsibilities to decide the problem, they would also actively engage in the problem later. In his sense, this is not only make the students actively, but also teach them about the expected attitude to the problem.

In addition, Runco (1994) also discussed the importance of problem finding. He compared the present problems and the discovered problems. With Okuda (Runco & Okuda, 1988), he found that discovered problems led more solutions and Okuda (1991) suggested that creativities should be assessed with the discovered real-world problems and the tasks of problem findings should be identified (Runco, 1994).

The questions usually have given or prepared by teachers. The reason seems to be similar as Umene (1977) suggested, "The more educators respect the students' life and students pursue what they want, the more class become instantaneous." Definitely, a solution needed here.

Therefore, the author and colleagues tried to give the students such opportunities to define the real-world problems by themselves (Saito, Gunji, & Kumano, 2015; Saito & Kumano, 2015). Although it was very less samples, more than 85% of students (85.2-100%) can decide the engineering problems by themselves. In addition, in such situation, stories about related technologies support the definition of engineering problems. However, the studies did not identify the specific task characteristics in problem findings in SILE, yet.

Integration in the 1950s Discussion

The discussion in this era summarized into two big topics about core curriculum and the integrative education.

The ideas of core curriculum root in European countries especially in Germany with the researchers like Chiller. The researchers in the US, Mcmarray brothers, or de Garmo, learned them from Germany (Umene, 1977). From their trial for core curriculum development, there were several suggestions for this STEM era could find. The National Society for the Study of Education (1947) reported in its 46th Year Book that the new idea and sequences of core curriculum approach provides beneficial opportunities but the majority of schools focused on social studies in its curriculum. Thus, even though science teachers helped on the curriculum development, the science learning materials did not be integrated with English language arts and/or social studies. The committee claimed that the science teachers have the responsibilities which deciding the curriculum direction. How can we do it in the era of STEM education?

On the other hand, in the 1950s, there was a discussion about how integrative approaches would be feasible. Hantz (1950) who was an attendance of "Stillwater Conference" reported that there was a discussion that "the integration of knowledge needs to be prior to the integrative education" (Northrop & Margenau, 1950). This idea is very similar to the notion of Discipline. In 1960s, the discipline meant that knowledge that teachable (Phenix, 1963). If integrative approach needs the knowledge integration previously, the education becomes more like discipline-centered approaches (Saito, in press).

To overcome this point, the educators need to solve the paradox that although they need to define exactly what they teach for class preparation and standards alignment, student-centered learning comes from students' interests, not from preparation of that discipline (Saito, et al., 2016) and to consider the Transdisciplinarity.

Challenges in STS Era Particularly by 1990s

The term Transdisciplinarity, had discussed in 1990s, also was a topic in the effort for developing integrative approaches. It can be seen as a set of discussion on the mode of inquiry (Schwab, 1964) and the change of view about discipline. The author had arranged the discussion in this era.

.. from the perspectives of "Science, Technology, and Society" (STS) and the nature of science, discussions took place about how science and society affect each other (Gibbons, 1994; Hurd, 1958, 1991, 1998; Kuhn, 1962; McComas, Almazroa, & Clough, 1998; Yager, 1980, 1996), and theories for the basis of integration were developed. Especially in the 1980s and 1990s, integration and redefinition of disciplines were discussed in terms of STS (Bybee, 1987; Good, Herron, & Renner 1985), sometimes-called SMET: Science, Mathematics, Engineering, and Technology (D'Ambrosio, Black, El-Tom, Matthews, Nebres, & Nemetz, 1992). According to those studies, we can also find some suggestions for describing learning with trans-disciplinary problems (issues). Those who struggle with a trans-disciplinary problem will work with those in other disciplines or with other stakeholders beyond the discipline. In this situation, because of the problem being decided by the application context, people work in different theoretical frameworks, methods, and styles of research from individual disciplines and often do not return to the rigor of their own disciplines (Saito et al., 2016).

In such transdisciplinary approaches, *Issues* decided the *Context* of the *Application* and *Communications* among the researchers are very important (Gibbons, 1994).

STEM Integrated Learning Environment

According to the discussions on the transdisciplinary approaches, the author and the colleagues (Saito et al., 2015ab, 2016) have provided three frameworks to identify the STEM Integrated Learning Environment (SILE) for their Shizuoka STEM Junior Project that was integrating science, technology, engineering, and mathematics in the activities. The three frameworks were Ecology of SILE (Saito, Okumura, & Kumano, 2016), T-SM-E method (Saito, Gunji, & Kumano, 2015), and Theories for SILE (Saito, Anwari, Mutakinati, & Kumano, 2016) and indicated on the Figure 2-1. & 2-2. While those three components had already developed through their project 2013 and 2014, the research on the project 2016 did not focus them. However, those are the basis for developing the activities for this study.

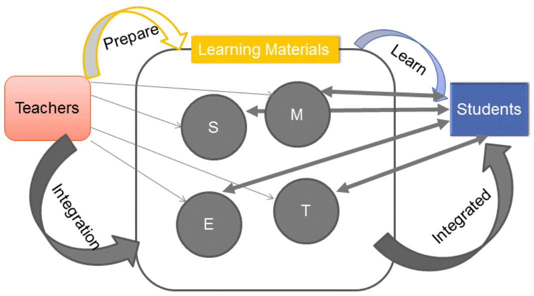

Figure 2-1.Ecology of STEM Integrated Learning Environment

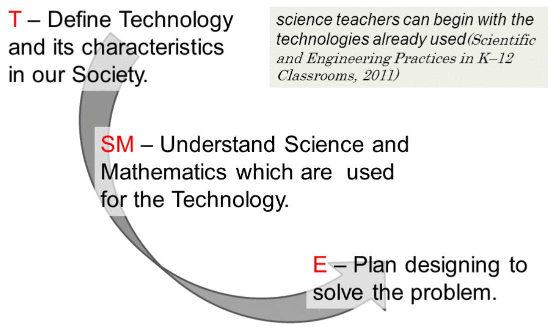

Figure 2-2. T-SM-E method for Developing Leering Materials

Those two figures were developed from the slides for ASTE 2016 by Saito, Okumura, & Kumano, 2016

As the conclusion for the Integrative Approaches in STEM era, the theories for SILE suggest the appearance of learning in STEM Education.

> *Learning in the STEM Integrated Learning Environment has certain features: 1) learning is not necessarily included in and assessed by disciplines as in traditional classes; 2) learning within and across networks of learners has relationships beyond STEM disciplines; and 3) thus, the environment would be structured by vectors of those relationships. If so, teachers are expected to prepare for interactions among STEM areas of learning* (Saito et al., 2016).

This understanding of SILE is also considered to develop the Shizuoka STEM Junior project for this study.

CPS As the Heuristics for Real-World Problem Solvers

In this section, the author arranges the transfer issues related to the ideas of creative problem solving and states four research questions by identifying the problems around heuristics.

21st Century Skills as "Generic"

The 21st century skills were very similar to the idea of generic skills that has been discussed in the higher education area and they expected the employability and transferability. Yoshihara (2007) and Kubota (2013) had already arranged how other countries dealt with such skills or competencies and the value of such education nurturing them. As they arranged, some of the organizations had introduced creativity as such generic skills.

On the other hand, National Research Council (NRC) held a workshop to develop constructs for assessing 21st century skills. In the discussion on the workshop summary, those skills include creativity, on Table 2-1. were examined.

Table 2-1. 21st Century Skills Which Examined by NRC (2011)

Cognitive Skills	nonroutine problem solving, critical thinking, systems thinking
Interpersonal Skills	complex communication, social skills, team work, cultural sensitivity, dealing with diversity
Intrapersonal Skills	self-management, time management, self-development, self-regulation, adaptability, executive functioning

At least, creativity and critical thinking skill were discussed their domain specificity among such skills that called generic (Bear, 1993; Koening, 2012).

Such generic skills were assumed that they could not be nurtured through the academic education (Kubota, 2013) and were expected to develop across the subject matter (National Institute for Educational Policy Research, 2002). However, if they have domain specific character, every educational activity, which expects to transfer such skills across domains, need to be considered.

How Transfer Expected

In the early researches, there were not enough evidences of transferring learning contents, but of applying some skills that well trained to other context (e.g. Thorndike & Woodworth, 1901; Salmon & Perkins, 1989).

Among the research, Bruner suggested Intellectually Honest Way of teaching and the transfer on the Structure of discipline (Bruner, 1961). Lawson (1989) who suggested Learning Cycle obtained the evidences supported the transfer of learning with the cycle. Although such learning flow could be find from Dewey (1910) through the problem solving, heuristics, discovery-learning model, and/or scientific method, the researchers in STEM era casted doubt on such general approaches. They resisted fixing new procedures that students march with it and teachers use of them for instruction, because scientist engaged in complicated messy activities: Cascades of Practices (Bell &Van Horne, 2011; Bell, Bricker, Tzou, Lee, and Van Horne, 2012). Is the transfer of contents or structure, promoted through such unfixed procedure of inquiries?

How can we assess them?

Next, if those skills do not have generality, what would be expected? First, there was a possibility that, as well as the other knowledges, the skills just could be applied to the context physically similar, although they were expected to transfer to the different context (Brown, 1990). Second, if students learned through different skills in different domain, the way of assessment must be different each other.

For example, the Consensual Assessment Technique (CAT) had already been used by the researches on the assessment of creativity who claimed the domain specificity depended on the assessment of experts in each domain. In addition, Bear (1993) had suggested task specificity with CAT. Moreover, the followers on his work examined the specificities on other tasks and the possibilities of assessment by the quasi-experts.

Those are the summary of the discussions about the transfer and domain specificity. On those matters, you can find such four aspects of discussions as **transfer and learning, process of learning, and their assessment**. The discussions bellow deal with such aspects, and specify and partially answer the question or problems related to them.

The Creative Process and Creative Tasks

By learning from the history of heuristics, the author hypothesized that the eight practices which were suggested in the Next Generation Science Standards (NGSS Achieve, 2013) were not a sequence of learning but the cascade for the students' learning in their independent inquiries (Chin & Osborne, 2007; Pratt, 2013). That was also a claim by Bruner (1961) who suggested the heuristics as not a single way of conducting inquiry. By discussing them, the author claims the role of heuristics for the real-world problem solvers.

What is the Heuristics?

The term, Heuristics, was a suggestion by Bruner (1961) who was the very first personnel in the cognitive science. In his notion, the heuristic was "*a nonrigorous method of achieving solutions of problem*."

List of Processes in Problem Solving Approaches

From the late 19th C. through the early 20th C., the problem solving approaches were suggested and Russell (1956) gave these lists of problem solving approaches (Table 2-1.) and the author arranged them on the table.

First, as appeared on the Table2-2, different people suggested different type of sequences, although those approaches seemed very similar. From those descriptions, it is difficult to assume there is one fit all type of process. Actually, it is usually misinterpreted as a fixed sequence of steps (AAAS, 1991)

Table 2-2. Lists of Processes in Problem Solving Approaches

Dewey (1910)	Burt (1928)	Gray (1935)
1. "A felt of difficulty"	1. Occurrence of a perplexity.	1. Sensitivity to problems.
2. Its location and definition	2. Clarification of the perplexity.	2. Knowledge of problem conditions.
3. Suggestion of possible solution.	3. Appearance of suggested solutions.	3. Suggested solution or hypothesis.
4. Development by reasoning of the bearings of the suggestion.	4. Deducing implications of suggested solutions.	4. Subjective evaluation.
5. Further observation and experiment leading to its acceptance or rejection.	5. Verifying action or observation.	5. Conclusion or generalization.

Table 2-2. Continued

Johnson (1944)	Polya (1945)	Humphrey (1948)
1. Orienting to the problem. 2. Producing relevant material ("search"; "free play" of thought)	1. Understand the problem. 2. Make a plan. 3. Carry out the plan. 4. Look back on the completed solution (plus a looking list of "mental operation").	Directed thinking involves: 1. A problem situation. 2. Motivating factors. 3. Trial and error. 4. Use of association and images. 5. A flash of insight (The place of 3, 4, and 5 varies with the problem). 6. Some application in action.
Bloom (1950) "Problem-solving characteristics" are: 1. Understanding of the nature of the problem. 2. Understanding of the ideas contained in the problem. 3. General approach to the solution of the problem. 4. Attitude toward the solution of the problem.	Burack (1950) 1. Clear formulation of the problem. 2. Preliminary survey of material. 3. Analysis into major variable. 4. Location of crucial features. 5. Application of experiences. 6. Varied trials. 7. Control. 8. Elimination of sources of error. 9. Visualization.	Vinacke (1952) 1. Recognition of the problem. 2. Manipulation or exploration of some kind. 3. Analysis. 4. Partial solving. 5. Emotional responses.

Extracted from Russell (1956)

Heuristics Approach on the STEM Creative Problem Solving (CPS)

As Bruner (1961) suggested, it is difficult to suppose that general heuristic that is applicable for more STEM situations available. However, before Bruner suggest, there were many sets of heuristics proposed. Some of them supposed that they could applicable for the well-structured problem as well as creative problem solving (CPS). By examining each definition of heuristics on CPS one by one, the author argues here how heuristics developed through the engagement with the non-routine problem solving.

First, although the basic idea of divergent thinking had been developed by Guilford (1956), Osborn (1954) also suggested brainstorming that is widely applied in the industrial world. Although his aim was application of creative problem solving to the engineering activities in General Electric (GE), the idea brain storming also affected by and to the expansion of divergent thinking (see also the next section: Characteristics of CPS). If you look at his first print of "*Applied Imagination,"* you can find that his idea came from a mathematician Poincare (Osborn, 1963). However, it is apparent that his heuristic was affected by Wallas (1926) who wrote about Poincare's story of problem solving (about Fuchs equation) in the "*Science et methode*" (Poincare, 1908) as indicated in Table 2-3. Both Wallas and Osborn stated that the "*Incubation*" phase exists and it affected on the principle of creative thinking that "*postpone of judges*" (Osborn, 1963).

Table 2-3. Heuristics in CPS

Era	1908	1926	1954
Researcher	Poincare	Wallas	Osborn
Heuristics			1.Orientation
	1.Preparation	1.Preparation	2.Preparation
			3.Analysis
			4.Ideation
		2.Incubation	5.Incubation
	3.Illumination	3.Illumination	
			6.Systhesis
	4.Validation	4.Valification	7.Evaluation

Although judicial thinking was not denied in his sentences, the widely applied idea of brainstorming and postponement of judges accepted in the area of education. However, it was important to note that as Osborn (1954) claimed the creativity spoiled if the thinker did not know when and how those thinking, creative, and judicial thinking, were applied.

In addition, it was pointed out that those heuristic approaches were not just the revision of problem-solving approaches and actually, there were such critiques that "they were almost the same as problem-solving" or "it was the same as spontaneous learning" (Fujii, 1967). The answers to all those critiques concluded in the following sections as transfer issues.

The Characteristics of CPS

This section discusses the characteristics of creative problem solving (CPS). The topics are; Why CPS needed; Problem findings in creative problem solving; Divergent thinking and the Torrance Test of Creative Thinking; and Judges on Creativities and Consensual Assessment Technique. These discussions arrange the issues around heuristics and task specificity of creativities.

Why CPS Needed?

As a 21st Century Skills, creative problem solving (CPS) skill has the different name that "non-routine problem solving" (Koenig, 2011). While CPS skill usually works with ill-structured problem or unfamiliar problem, the non-routine problem solving needs to be taken as a set of function to struggle with such unfamiliar problems (Lai & Viering, 2012). In this section, the author discusses how do they related and why CPS is needed.

As discussed above, the real-world situation has been advocated among STEM educators (Bybee, 2011, 2013; Dewey, 1899; Fensham, 2009; Osborn, 1963; PCAST, 2010, 2012) and if students would be engaged in such integrative learning environment, they needed to conduct their inquiries with such heuristics that might specific to their each inquiry (practice) (Bruner, 1961; Chin & Osborne, 2007; Pratt, 2013). Furthermore, if they engage in the engineering design activities, the cycle of learning would be iterative (NGSS Achieve, 2013) as explained in the Next Generation Science Standards (NGSS), Appendix I. In such situation, they do not just follow the specific sequence of heuristics; rather they need to select the next steps if an approach does not work (Levy and Murnane, 2004). The researchers called this "non-routine problem solving."

Problem Findings in Creative Problem Solving

If we look at the starting point of CPS (see also PBL section above), the problem finding part needs a discussion.

In their study, Runco (1994) tested the combination of divergent thinking (DT) and the problem finding (PF). They called it as Discovered Problem Divergent Thinking Task and asked subjects go back to look at the list of problems in their schools or work places and select the problem that may generate most solutions.

Divergent Thinking and the Torrance Test of Creative Thinking

In the history of assessment of creative thinking, it had assumed that the "person has creativity"(Guilford, 1950). However, many researches of creativities actually used "solution" or "product" to assess their creativity (Bear, 1993). On the other hand, as discussed above, the research of creativities, particularly in psychology, also focused on its creative processes (Bailey, 1979). Bailey explained that the CPS was the mixture of the creative process and its product. However, if we focused on such creative process, it had assumed that anything produced by such creative processes had been called creative (Amabile, 1996).

Bear (1993) considered such situation and claimed that divergent thinking, which has been widely accepted, needed to be revised and that task specific approaches are needed. The fundamental doubt on the divergent thinking theories were came from its confusion between general use of such theories and claims by their developer such as Guilford (1967) and Torrance (1966).

For example, four categories of divergent-production factors (Guilford, 1967), fluency, flexibility, originality, and elaboration, were usually used in the research of creativities and Torrance Test of Creative Thinking (TTCT) provided those scores separately. Unfortunately, the test also has been used to indicate total score as the synthesis of such sub scores. However, if we look back the factor analyses of Guilford (1956), such sum total of the separated scoring of sub scales were not assumed (Bear, 1993).

Then, Bear himself adopted Consensual Assessment Technique (CAT) that had developed by Amabile (1982).

Judges on Creativities and Consensual Assessment Technique

To have the rationale of CAT, going back to the discussion of judicial thinking is needed. Runco had discussed about evaluation skills that judges should be judged. However, who judges judge, and who judges judge's judges (Runco, 1994)? On this point, he referred the culture of peer-review system and claimed that scientist were usually taking emphasis on the value of peer-review, the same scientists usually overlooked the statement of value as unscientific or non-systematic. Runco also valued that some journals, on the other hand, showed refries' name on their publication.

The consensual assessment technique selects the experts from the relevant field and explains they are the most appropriate judges of creativity in the domain (Kaufman, Bear, Cole, 2009). In this sense, creativity means "A product or response is creative to the extent that appropriate observers independently agree it is creative." On that basis, Bear (1993) confirmed domain specificity rather task specificity on storytelling, poetry writing, word problem creating, and collage making tasks by using this CAT.

Task Specific approach for STEM Inquiries (Practices)

Task Specificity of Creativity in STEM CPS

As Bear (1993) suggested, if there are domain specificity or task specificity of creativities in STEM education domain, what will be expected? Although he examined art type of products, storytelling, poetry writing, and collage making, does task specificity applicable to the product of STEM CPS?

Bear also suggested that if one is not trained to use divergent thinking in the related situation with creativity, the skill affects less on the creative performance. However, it cannot teach commonly to the students and actually has not recognized as important creative skill by students (Bear, 1993). Thus, the student's recognition when the divergent thinking skill can be used is more important than how the students have the skill itself (Bear, 1993).

Heuristics in STEM and Cascade of Eight Practices

In addition, if go back to the discussion of heuristics, this task specificity also has relationship with the sequences of learning. As Pratt (2013) suggest, the eight practices on NGSS (Table 2-4; NGSS Achieve, 2013) would be cascade type of heuristics. Thus, students would follow them back and force and each student may have different trace of learning when the inquiries will be reflected. On this point, there were very limited literatures. However, the discussion among problem solving or heuristics had similar problem that should be solved. **Even though those approaches had been suggested as "not the perfect model," they had been the only one model when they applied to a classroom. Thus, this study also should be kept as student-centered and integrative learning environment to confirm the rarities of such approaches.**

Individual Narrative of Creative Thinking

As a respond to such discussions above, Driver (1983) suggested that the students in secondary level understand the rules of the game soon and ask, "Is

Table 2-4. STEM Eight Practices on Next Generation Science Standards

1	Asking questions (for science) and defining problems (for engineering)
2	Developing and using models
3	Planning and carrying out investigations
4	Analyzing and interpreting data
5	Using mathematics and computational thinking
6	Constructing explanations (for science) and designing solutions (for engineering)
7	Engaging in argument from evidence
8	Obtaining, evaluating, and communicating information

this possible to happen?" or "the solution of mine is the correct answer?" The heuristic approaches had a confusion that they asked to inquire, gathering data, and developing reasoning from them, although it was intended to find the scientific law or principles that are accepted currently. However, as Yager (2014) stated, "doing science" is not the one just reading textbooks, working in laboratories, and taking tests by memorizing, but starts from personal problems and propose concrete results. If so, the students are not just follow the sequences that teachers suggest, but begin with the internal-motivation of the students.

Amabile, who suggests the consensual assessment technique (CAT: see prior sections), argued this point and distinguished the heuristic tasks and algorithmic tasks (Amabile, 1983). The fixed sequences, which suggested in this chapter involves algorithmic tasks. Although it is not revealed if Amabile recognized task specificity, things what this research need to find are heuristic tasks and there is a possibility that they related to the individual learners.

Chapter III: Research Methods

Chapter III provides the details of research design, methodology, and methods employed for this study. Those are planned to answer the research questions that:

(1) How task specific approaches improve students' creativity in the extent of Torrance Tests of Creative Thinking that was applied to the area of integrative Science Educations or its STS approaches?
(2) Are the students' creativity assessed differently in each area of STEM?
(3) When students engage in the STEM independent practices, how do they follow the cascades of eight practices? Are they different within/among groups?
(4) What kinds of potential creative tasks do students show during their own cascade of inquiries (practices)?
(5) If students realize the task specific divergent thinking, where & when do they apply it to their own inquiries (practices)?

This chapter includes those sections bellow. (a)Methodology: why mixed method approach is appropriate for this study; (b)Methods: details to conduct this study by describing ① Map of conjecture for total perspective, ② Embodiment of high level conjecture in Shizuoka STEM Junior Project, ③ Medicating processes to develop the design outcomes via design conjectures, and ④ Outcome which would be arranged via theoretical conjectures; (c) Assumptions and Limitation of This Study.

Methodology

In this section, the author explains why those methods have been employed. First, this study employed mixed methods approach (Creswell and Clark, 2007) because this study, by nature, had mixed research question that should be examined by both qualitative and quantitative analyses.

As the author mentioned in the previous chapters, researchers usually assessed creativity in the quantitative methods and identified that creativities which assessed differently in different domain and the different tasks by the products (Bear, 1993). In addition, it has been confirmed in many contexts (Bear & McKool, 2006; Hennessey, Amabile, Mueller, 2011; Kaufman, Lee, Bear, Lee, 2007; Plucker & Runco, 1998). In those studies, the researchers employed Consensual Assessment Technique (CAT) and Torrance Test of Creative Thinking (TTCT) as their method. However, as Bear (1993) suggested, if those results are correct, the tasks that related to the STEM practices exist and it should be specific for each person.

The experiments and the results on creativities are very similar to the result of research in “transfer” issues (Brown, 1990; Lawson, Abraham, and Renner, 1989; Shirouzu, 2012). If we take it as the transfer of learning in creativity, the divergent thinking skills, even if it was the revised definition of divergent thinking (Bear, 1993), will not transfer as educators expect (Labato, 2006).

Thus, the author stated hypothesis based on the understanding that students’ learning on creativity in SILE would have multiple pathways as they apply the divergent thinking skill to their own inquiry. As stated in research hypothesis, there must be their own stories that bring divergent thinking skill into students’ own inquiries.

Thus, the author confirmed the quantitative fact, and tried to explain the applications of students’ creative approach via qualitative method. As the author tried to identify the tasks for STEM creativity, the eight practices (see chapter 2) could be employed. However, if we think it as the learning progressions of students on divergent thinking, the constructs had never been identified by the bottom up approaches.

Therefore in this study, the author employed triangulation design: convergence model among mixed methods approach (Creswell & Plano Clark, 2007). As indicated in the Figure 3-1, which was developed on Creswell & Plano Clark (2007, p.70), the triangulations design: convergence model has two apparent parts. In the first part, the author took quantitative data, analyzed, and arranged them. On the other hand, in the second part, qualitative data was taken, analyzed, and arranged from the same subjects. In turn, those results were compared and interpreted. In this model, both quantitative and qualitative analyses are put emphasized (as indicated in capital).

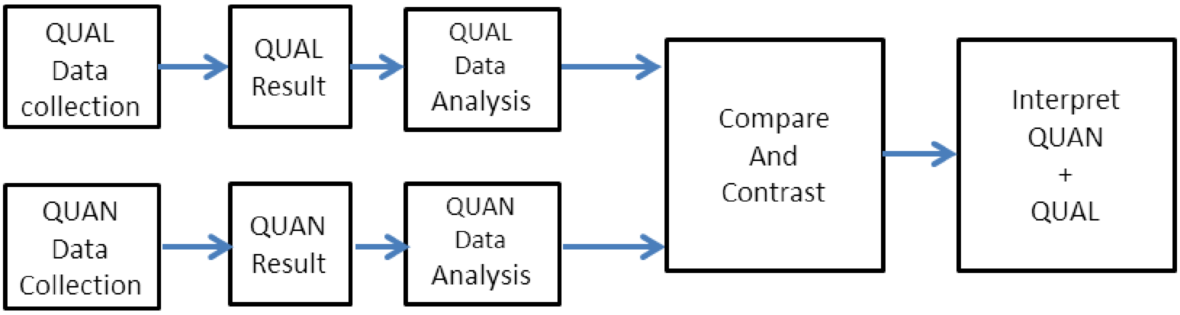

Figure 3-1. Procedure of Mixed Methods Analyses (from Creswell & Plano Clark, 2007)

Methods

This section provides how this research is conducted on design-based research with the mixed methods approach and how the data is examined. The details include the explanation of conjecture mapping, high-level conjecture, embodiment, design conjecture, mediating process, theoretical conjecture, and outcomes of this study.

Conjecture Mapping

This study adopted Conjecture Mapping (Sandoval, 2014) to make the description argumentative grammar and to develop systematic approaches to the conduct of design research (Brown, 1992; Collins, 1992). Mapping the conjecture guides, a design can guide the systematic test of particular conjectures about learning and instruction in specific contexts (Sandoval, 2014). Thus, in the following part of this section, the author discusses the method for this study based on the conjecture map on Figure 3-2. The map has six major elements and their relationships. The elements are High-level Conjecture, Embodiment, Design Conjectures, Mediating Process, Theoretical Conjectures, and Outcomes. Among such elements, the design conjectures connect embodiment and

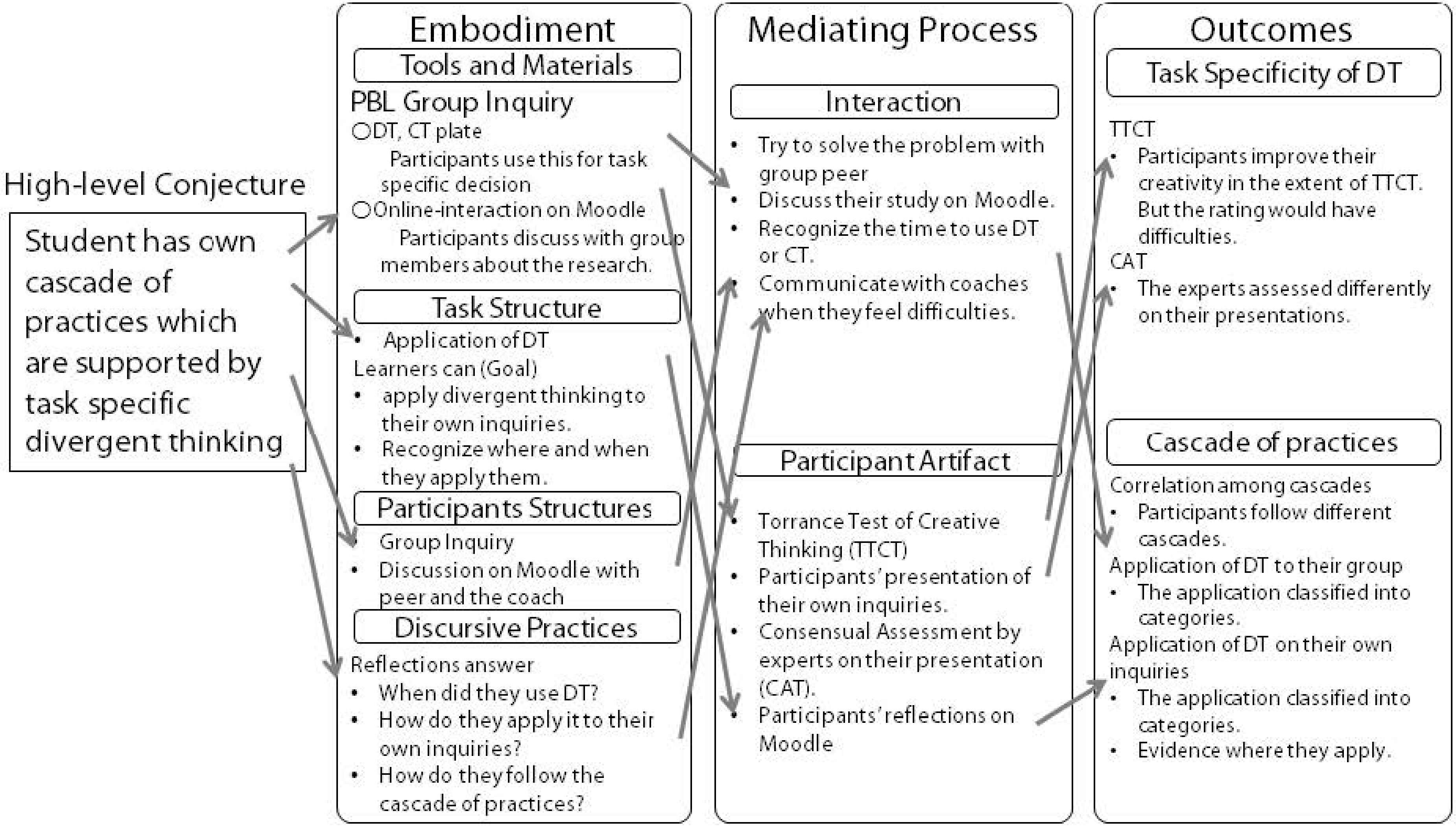

Figure 3-2. Conjecture Map for This Study

mediating process and the theoretical conjectures connect mediating process and outcomes.

This study was conducted on the notion of PBL (Project based Learning) approach in STEM Integrated Learning Environment (SILE; Saito & Kumano, 2015; Saito, Anwari, Mutakinati, & Kumano, 2016). Each part of this section bellow refers the explanation of Sandoval (2014) and specifies the contents of the conjecture mapping for this set of environments that PBL and SILE (Figure 3-2).

High Level Conjecture

This design-based study conducted on the high-level conjecture (Sandoval, 2014) that "Student has own cascade of practices which was supported by task specific divergent thinking". This high-level conjecture supported all of designs and conjectures in this study.

Embodiment

For the embodiment part, the learning environment will be developed based on the high-level conjecture that "Students has own cascade of inquiries (practices) which were supported by task specific divergent thinking". In addition to the elements of conjecture mapping (Sandoval, 2014), the author explains the details of their project as "Context".

Context

This study held the activities in the class for Shizuoka STEM Junior Project that invited students from fifth in elementary through ninth in middle school grade levels. This project has been held by Shizuoka University with collaborating with Shizuoka Science Museum called Ru・Ku・Ru, lifelong learning division in Fujieda city, teachers self-training organization in Hamamatsu area, and some high schools and their teachers of Shizuoka Prefecture from 2013.

In 2014 and 2016, they got the project grant from Japanese Science & Technology Agency called "the Future Scientist Program". This study particularly focuses on the activities in 2016.

The Shizuoka STEM Junior Project required the participants who had experience to get a prize from prefecture level or to get two prizes from city level competition, and they voluntary joined the project. They had experienced their own inquiry through this project and had started to focus creative problem solving program from 2013. Thus, generally speaking, these participants were familiar with the activity of inquiry.

The proportion of the grade levels were indicated in Table 3-1. The middle school students were four in 9th grade, five in 8th grade, and six in 7th grade. The elementary school students were three in 6th grade are involved. They were four female and 14 male students.

Table 3-1. The Proportion of the Students Who Joined The Project

Grade 6	3
Grade 7	6
Grade 8	5
Grade 9	4
Alumni (high school students)	3

Tool & materials

In this part of design, *tool & materials* would be software programs, instruments, manipulable materials, media, and other resources (Sandoval, 2014). In the Shizuoka STEM Junior Project, the programs conducted on Moodle as well as offline programs of each group meetings. Thus, here the author arranged the embodiment on meetings & moodle and explained specific elements of embodiment below.

DT/CT plate to support task specific approach

Though the group meetings, the task specificity secured by a "DT/CT Plate" (Appendix E), although it has not revealed what kinds of divergent thinking tasks will be done through the STEM project (CT: Critical Thinking). The Japanese descriptions on the plate referred to Fujii (1967).

Online-interaction on moodle

As a material for their group inquiries, Moodle was used as well as the discussions in the program of stage2. A Course was developed for the stage2 that included these Forums and Feedbacks in Table 3-2.

Table 3-2. Course Materials Prepared on the Moodle

Classes	Functions	Descriptions
Glossaries	Forum 1	News for Stage2
	Forum 2	Things which would like to do in each groups
	Forum 3	Toolbox to conduct creative group work
Group Work	Forum 4	Group Lab.
	Forum 5	The records of group inquiries
	Forum 6	Plan for the materials & related finances
	Forum 7	Schedule Forecasting by the timekeeper
	Chat 1	Group Chat Room
Information for the Stage2	Forum 8	Staffs Will
	Forum 9	Information by the alumni
	Folder 1	Photo Shearing
	Folder 2	Materials in each stage2 program
Reflective Tasks	Feedbacks	Reflection to think creatively (This Feedback renewed in each time and was written, thus 10 Feedbacks are actually developed.)

The terms that start in capital are the course functions on moodle (e.g. "Forum" is a function that allows participants posting a comment with attached files one by one).

Task structures

As indicated on Table 3-2. the participants engaged in the discussions and reflective tasks on those functions on the moodle. This *Task Structure* refers to the structure of tasks which learners are expected to do (Sandoval, 2014). Here the author explains how those tasks (goals, criteria, standards) are provided on meetings & moodle.

Application of DT

The application of divergent thinking (DT) expected to do in the meeting of group inquiries, in the discussions on the moodle, and in struggling their own independent inquiries.

Though the group meetings, the task specificity secured by a "DT/CT Plate" (Appendix E), although it has not revealed what kinds of divergent thinking tasks would be done through the STEM project (CT: Critical Thinking). The Japanese descriptions on the plate referred to Fujii (1967).

In discussion on the moodle, the participants expected to use creative/critical thinking and asked to use 【】for the record of their use. For example, when they started the discussions on Chat function, a member put 【creative】or 【critical】on the first sentence. In addition, the author provided eight practices from NGSS on the moodle (Forum 3 on Table 3-2). The author intended to provide them as heuristics. Thus, they did not explicitly appear as the discursive practices on stage2, rather, just provided on a moodle page. Those two examples above were the learning of applications of divergent thinking where and when they could be used.

On the other hand, the author expected they would use them in their own independent inquiries. Their inquiries continued along with the group inquiries. Thus, this task expected to transfer from their learning in stage2 to their own.

Participant structures

The *participant structure referred to how participants were expected to participate in tasks, the roles, and responsibilities they took on* (Sandoval, 2014). Here the author explains how stage2 activities provided the structures in the program and on moodle.

Group CPS project-based learning

First, the Shizuoka STEM junior project has provided project type of learning environment from 2013 school year (Saito, Kumano, 2014). The difference from problem-based learning is the focus on the product as an outcome from the project rather than the process as problem based learning do (see Chap. 2; Kain, 2003). Thus, in this STEM junior project, the development of the solution is very important to accommodate students' learning and the authors analyzed the solutions developed through the activities (Saito, Okumura & Kumano, 2014; Saito & Kumano, 2015ad).

The project, prior to the school year of 2014, had separated into two parts and their objectives. The first part, STEM Classes, had provided STEM practices and aimed to prepare students familiar with creative problem solving program. On the other hand, the second part, had provided advises supporting students' own independent inquiries (Saito & Kumano, 2015d).

In the school year of 2016, the project progressed into the second phase and added a program called "Stage2" that providing the independent inquiries as the main part of the learning environment. Because, the participant themselves had gradually got into familiar with the independent inquiries and many of them had been prized on the local prizes. Therefore, the Stage2 provided the opportunity of project-based group inquiries and students engaged in their projects.

Table 3-3. The Schedule for Shizuoka STEM Junior Project Stage2

Dates	Program
15th May	Opening ceremony, participants' presentations, and TTCT & CAT pre-test in morning. Brain storming on questions/problems of the participants, deciding some questions/problems that they want to quest and dividing groups in the afternoon.
29th May	Defining the problem for the group inquiries and predicting the future schedules.
11th June	Group Inquiries 1: material preparation, finance, and defining problems etc.
18th June	Group Inquiries 2: mediate presentation and group discussions
9th July	Group Inquiries 3: group discussions
22-24th August	Group Inquiries 4: experiment / observations etc.
3rd September	Group Inquiries 5: group discussions
17th September	Group Inquiries 6: experiment / observations etc.
15th October	Group Inquiries 7: continue
29th October	Group Inquiries 8: continue
12th November	Group Inquiries 9
23rd November	Participants' presentations, closing ceremony

The Table 3-3 above shows the summarized program and the schedule.

The participants decided their group with brainstorming their questions/problems in the first time of the program on 15th May. The group and the problems developed on that day were indicated in Table 3-4. The specific procedure how they thought up and decided their questions/problems indicated in Figure 3-3.

Table 3-4. The Questions/Problems Which Asked in the Group Inquiries

Groups	Questions/Problems
A	Developing clothes which would not have any stain.
B	How can we make carbon dioxide change to oxygen?
C	
D	Developing a machine that let us talk with animals.
E	I would like to fly on the sky using soda

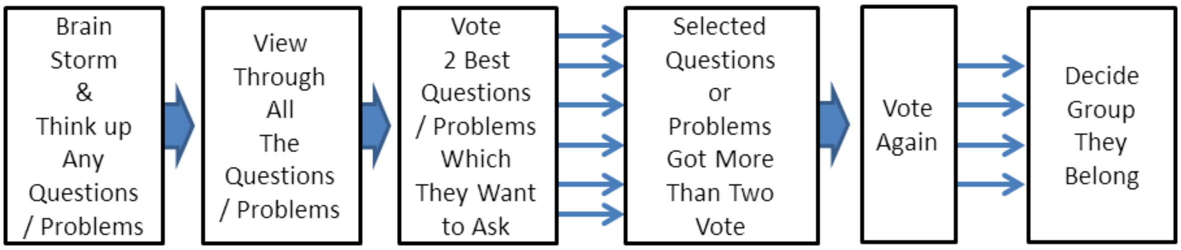

Figure 3-3. The Specific Procedures How They Think Up and Decide Their Questions/Problems

At first, the participants raised their "real-world" questions or problems on the brain-writing method that allowed them more responses. As the result, they thought up more than 200 questions/problems. After that, they looked at all of those questions/problems by rotating their worksheets. Next, they voted two best questions/problems they wanted to ask and may have more solutions (Runco, 1994). The questions/problems that got more than two votes were selected once, because the populations were relatively small. After they have voted again, the participants selected their group that they would to ask in this year programs.

Based on this brainstorming, they pursued their own questions/problems from the next session.

Group inquiries (practices)

The group inquiries (practices) in the stage2 expected to be conducted by the participants themselves. Thus, the educators had minimum interventions (see also the Discursive Practices below). The groups of participants were engaged in the discussion how they were going to solve the questions/problems. Each member had the role as moderator, timekeeper, financial person, and material coordinator. When they had questions or have what they want, they asked the educators (they are called coach). The coaches included Ph. D. students and graduate students in master level.

Discussions on moodle

Also on moodle, the discussions of groups were distinguished by the function of moodle. Thus, the participants only focused on the discussions of each group in the prepared Forums and expected to continue their discussions between the sessions.

Coaching through the program

The coaches expected to work with the participants with minimum interventions. Thus, the participants naturally felt difficulties because it was the first time for them to conduct the independent inquiries (practices) with their peer as group inquiries. Prior to the program, the author recognized that when it is the problem of technology (called technical problem), the seeking of scientific regularities was disturbed (Saito, Gunji, Kumano, 2015). Therefore, the author decided to support them only on such technical problems and the difficulties expected to overcome by themselves. Because the difficulties also were expected, become the anchor of inquiries (Dewey, 1910; see Table 2-1).

Experts' assessment on their presentations

The participants made presentations on the first time and last time session (Table 3-3). The experts of natural science, technology, and science education were joined the project for Consensual Assessment Technique (CAT) and assessed participants' presentation as the product of the projects and their own independent inquiries. Some other undergraduate students also joined as the quasi-experts for the assessment on CAT.

Discursive practices

Through the program of Shizoka STEM Junior Project, the participants were expected to do their group inquiries by themselves. The educators continued to retention the use of divergent thinking and critical thinking by using DT/CT plate. Such discursive practices were the basis of the design of this study.

Design Conjectures

The design conjectures provided *the ideas that how embodied elements of design generate the mediating processes could be articulated* (Sandoval, 2014). Thus, in this case of design-based study, the author stated such design conjectures bellow.

- The STEM PBL projects provide opportunities for developing their creative skills through helping the application of divergent thinking where they need to apply. Because, they definitely get in trouble to think up their solutions.
- The DT/CT Plates support the participants to decide when and where they apply the divergent thinking through their inquiries (practices). In addition, this task structure helps the educator to limit their interventions. Thus, this task actually supports the participants' structures and task specificity through the project.

Mediating Processes

The mediating processes were intended to produce desired outcomes and the process could be understood via two ways of explanation (Sandoval, 2014). The first way, *Observable Interactions*, provided how embodied elements of the design mediate the interactions with the participants. The second way, *Participant Artifacts*, was the artifacts that were produced through the sort of activities and proxy the mediating process. The analyses provide how participants interpreted and engaged in the set of structures and tools of environment, and explain how they performed in the activities.

Observable interactions & participants artifacts

The participants' interaction observable with this design on DT/CT plate as explained above, on using of 【 】 on moodle, and the reflections of using application of the divergent thinking which were also appear on the moodle as their artifacts. Those interactions and artifacts mediate and analyze the learning in this designed learning environment. The following part of this section explains how each interactions and artifacts were analyzed to make the expected outcome.

Torrance test of creative thinking

In the first phase of the quantitative analyses, the author employed the application of Torrance Test of Creative Thinking (TTCT; Yager, 1989; Yager& Tamir, 1993; Kumano, 1993) as the method. As discussed in Chapter 2, although the author expected the difference of assessment on CAT by the STEM experts, the program was also assessed on the traditional assessment technique to see the program impact on creativity.

Sample

The sample consisted of 6^{th} (3), 7^{th} (6), and 8^{th} (4) grade students from wide variety of schools in Shizuoka Prefecture. All 13 students were Japanese. The ages were ranged 11 to 14. Their experiences vary depending on their grade levels, because many of them joined the project from the 5^{th} grade.

Data collection and analysis

For this quantitative phase, the author conducted TTCT at the first time and the last time lesson in 2016. Questions, Possible Causes, and Predicted Conclusions were selected from TTCT according to Iowa Assessment Package (McComas & Yager, 1988), Yager (1989), and Yager & Tamir, (1993) whose study examined the effect of STS approaches on the creativities. Both pre-test and post-test were scored by five research assistants. The inter-rater reliabilities were taken for each task in pre-, and post-test.

Consensus Assessment Technique

As the second method for the quantitative analysis, the author employed Consensus Assessment Technique (CAT) as the method. As discussed in Chapter 2, the author had a hypothesis that the creativity in student's product had domain specificity, and would be assessed differently in different domain on Science, Technology, Engineering, and Mathematics. Thus, the author asked to experts of the domain of STEM and their properties are indicated in Table 3-5.

Table 3-5 The Raters of CAT in different domain of STEM and Their Professions

Experts Categories	Rater Number	Judged on	Their Expertized Domain
Experts	1	Pre & Post	Science Education (Earth Science)
	2	Pre	Science Education (Chemistry)
	3	Pre	Natural Science (Ecology)
	4	Pre	Natural Science (Developmental Biology)
	5	Pre	Natural Science (Earth & Space Science)
	13	Post	Engineering Education
Quasi-Experts	6	Pre & Post	Former Principal
	7	Pre & Post	Science Education
	8	Pre & Post	Science Education
	9	Pre & Post	Science Education
	10	Pre	Science Education
	11	Pre	Science Education
	12	Pre & Post	Science Education
	14	Post	Former Teacher
	15	Post	Former Teacher

Five experts include three natural science experts, and seven quasi-experts joined the pre-test as the rater. Two experts and seven quasi-experts joined on the post-test. The raters independently judged on the students' presentations on their own inquiries. The presentation was taken and was judged as the product of the inquiries. For the scoring, the 1 to 5 rating scale are adopted.

The pre-test was taken on the first day program soon after the opening ceremony and the post-test was conducted on the last day program soon after the closing ceremony of the Shizuoka STEM Junior Project.

Sample

The sample of pre-test consisted of 5th (1), 6th (3), 7th (6), 8th (5), and 9th (3) and the post-test consisted 6th (3), 7th (6), 8th (4), and 9th (1) grade students.

Data collection and analysis

In this quantitative phase, analysis of correlations with CAT was used in order to confirm the domain specificity of creativity in students' product of their independent inquiry. Data were gathered from the judges in first and last time session of the Shizuoka STEM Junior project. Quasi-experts also joined as the rater because some of the related study recommends employing quasi-experts for the feasibility of the study.

Record of Cascades

In the first phase of the quantitative analysis, the author also checked the trace of cascade among participants. As discussed in Chapter 2, the author had a hypothesis that the cascades of inquiry (practices) might different each other among the participants. Thus in this study, the difference were statistically examined.

Sample

The sample consisted of sixth (3), 7th (6), 8th (5), 9th (4), and 10th (2) grade students.

Data collection and analysis

In this quantitative phase, analysis of correlation was used in order to confirm the trace of cascade through their group inquiry. Data were gathered on Moodle with the reflections for the qualitative analyses.

Record of the application of divergent thinking

In the qualitative analysis, the author analyzed participants' record where they applied the divergent thinking. As discussed in Chapter 2, the author had a hypothesis that the participants applied the divergent thinking differently on their own inquiries (practices).

Sample

The sample consisted of 6th (3), 7th (6), 8th (5), 9th (4), and 10th (2) grade students.

Data collection and analysis

In this qualitative part, the participants' reflections on moodle were analyzed.

Although eight practices (NGSS Achieve, 2013) might work as the framework, the participants' descriptions were open-coded because the authors did not have any framework for the sub-categories as constructs under the eight practices. In addition, the selected coding was implemented particularly on the category 3 that indicates the possible tasks on the planning and carrying out investigations.

Theoretical Conjectures

The theoretical conjectures provide *how those mediating processes produce desired outcome* (Sandoval, 2014). Thus, these theoretical conjectures bellow are very similar to the research hypothesis of this study, but have more details.

If the mediating processes occur when

- the results of the application of TTCT provide the development of creativity in the STEM projects.
- the results of CAT provide the difference of assessments by the experts in the different STEM domains.
- the records of participants' cascade of inquiries (practices) provide the reality of the difference of the inquiries in-group setting.
- the records of when and where they apply the divergent thinking provide specific possible tasks for the next designs and assessments of the future works.

Outcomes

As the outcomes of this design-based study, those were evident from those analyses explained in the mediating processes. (a) the improvement of creativity in the extent of the application of TTCT; (b) difference of the assessment by the experts in the STEM domains; (c) traces of the individual cascade of inquiry (practice) in the group inquiries; (d) records of the applications of divergent thinking to the group inquiries and the transfer to the participants' own inquiries.

Assumption and Limitation of this study

Assumption of This Study

This study adopts task specific approach. Because the author assumes there would be significant differences on the correlation among the score of Consensual Assessment Technique (CAT) that will be assessed by the experts in the STEM area. This assumption based on the past example by Yager (1993) which examined the effects of STS approaches also developed integrative learning environment and by Bear (1993) which discussed domain & task specificity of creativities.

If Bear's discussion can apply to the domain & tasks in the integrative learning environment such as STS or STEM Education, the improvement of creativity in the extent of Torrance Test of Creative Thinking may encompass the difference of domain specificities. However, the test result does not mean the improvement of task specific creativities nor divergent thinking skills. To demonstrate this task specificity, the author needs to confirm the difference of judges by experts of STEM areas on CAT.

In addition, it has never been pointed out the task specific framework for the STEM creativities. Thus, the qualitative analyses along to the students' independent inquiries (practices) needed. As the result, this study extracts the STEM creative tasks that would be the points for improving students' creativity during their independent inquiries (practices), even if they do not cover all possible tasks.

Limitation of the Study

The limitation includes the samples on CAT, the familiarity of participants on the internet based system, and the understanding for the program by parents and the staffs.

At first for the CAT conduction, the judges should be experts in the domains of Science, Technology, Engineering and Mathematics and each domain should have enough number of judges to examine the inter-rater reliability. For example, Bear (1993) employed five experts for each test domain and took coefficient α. Although this study employed quasi-experts, the judges should be examined for the inter-rater reliabilities.

Next, this study deeply relied on the internet based learning system "Moodle" and its user interface. From past examples, the author knew that the internet-based system sometimes become constraints for the elementary and middle school students (Saito & Kumano, 2015d).

Finally, in this year, the Shizuoka STEM Junior Project aimed more student-centered approaches. Thus, the activities are completely unfamiliar to the participants, their parents, and staffs. Thus, there were the possibilities that there were unexpected effects to conduct such unfamiliar leaning environment.

Summary of Chapter III

In chapter III, the author provided methodology and the methods of this study. The methodology provided why this study employed mixed methods approach. The method was based on the theoretical framework that design-based research. Those methods explained relying on pragmatism and conjecture mapping. The mixed methods of triangulation: convergence model was used to combine the quantitative and qualitative analyses. The conjecture mapping utilized to arrange the specific design in the learning environment and to make the design had argumentative grammar.

Chapter IV: Quantitative Part- TTCT & CAT

This chapter IV arranges the result and discussions on the quantitative part of the study. Result 1 shows the result of Torrance test of creative thinking. Result 2 shows the result of consensual assessment technique. Result 3 shows the correlations among the participants' cascades of inquiries (practices).

Result 1- Torrance Test of Creative Thinking

The results of statistics on Excel 2010 for pre- and post- of TTCT are indicated in Table 4-1.

Table 4-1. Pre- and Post-test Data for TTCT

	Pre Test			Post Test					
	M	SD	α	M	SD	α	T	E.S.	power
1) Questions	8.62	3.25		12.00	4.53		-5.50 **	1.52	0.99
1-2) Unique Questions	2.09	0.94	0.80	2.74	1.12	0.75	-2.81 *	0.78	0.97
2) Causes	5.54	2.54		8.62	3.50		-2.90 *	0.81	0.90
2-2) Unique Causes	1.74	0.94	0.84	2.35	0.84	0.76	-2.29 *	0.64	0.88
3) Consequences	4.38	1.85		7.00	4.08		-2.68 *	0.74	0.83
3-2) Unique Consequences	1.18	0.67	0.82	1.46	0.67	0.43	-1.30	0.35	0.41

**p<.01; *p<.05 two tailed

As indicated in Table 4-1., the fluency of 1) question, 2) possible causes, and 3) predicted consequences (Yager, 1989; Yager& Tamir, 1993; Kumano, 1993) tasks were improved significantly (effect size= .74 – 1.52) and the uniqueness improved significantly (E.S.: effect size= .64 - .78) in those tasks except 3-2) consequences task.

However, it is important to note, from the Cronbach α (Cronbach, 1951), that inter-rater reliability in the Post-test did not valid (α< .80). In addition, from the power analyses on G*Power 3.1.9.2, fluency of consequences, and uniqueness of cause & effects and consequences did not have enough power (1-β> .90). Thus, the author employed Wilcoxson Signed Rank Test (Table 4-2.) for supplement.

Table 4-2. The Result of Wilcoxson Signed Rank Test

	Pre Test		Post Test		Wilcoxson Signed Rank Test		
	M	SD	M	SD	Wilcoxon's W	n	P-value
2-2) Unique Causes	1.74	0.94	2.35	0.84	12	12	0.02 < P < 0.05
3) Consequences	4.38	1.85	7.00	4.08	9	13	0.005 < P < 0.01
3-2) Unique Consequences	1.18	0.67	1.46	0.67	26	13	0.10 < P < 0.20

From the Wilcoxson Signed Rank Test, the uniqueness on 2-2) possible causes task and fluency of 3) predicted consequences task did have significant improvement in the extent of Torrance Test of Creative Thinking (TTCT), confirmed. However, the uniqueness of 3-2) predicted consequences task did not have significant improvement between pre- and post-tests. Finally, it is needed to make sure the 2-2) and 3-2) tasks did not have enough inter-rater reliability in the post-test.

Discussion 1- Torrance Test of Creative Thinking

From the result of the application of Torrance Test of Creative Thinking (TTCT), there are such three topics of discussion needed about improvement of participants' creativity in SILE, inter-rater reliabilities, and task specificity and the creativity test in science or STEM education.

First, in the extent of the application of TTCT, participants improved their creativity. However, in the predicted consequence task 3-2), the improvement was not statistically significant. If we take this result shows a single creativity factor, the STEM independent inquiries (practices) improved the participants' creativity. On the other hand, as research hypothesis stated, the divergent thinking could be applied to different moment and context for each person, those test could see as a set of three tasks creativities test. In such view, the questions and possible cause tasks had improvement and the predicted consequences task did not have enough training for improvement. In fact, participants' group inquiries (practices) did not achieve the phase of consequences in this year and thus their application did not happen on the consequences of the study. This will be confirmed on the qualitative part of Chapter V.

Next, the inter-rater reliability should be discussed. In this time, two graduate students scored and three undergraduate students re-test the rating of TTCT. In previous studies, the total creativity scores were tested their inter-rater reliability from 10% of samples (Yager, 1989). However, as this study also saw them as specific tasks for creativities, the reliabilities were checked on each task. The graduate students scored the pre-test with enough coefficients α, but the post-test did not have enough coefficients. The author considered that those graduate students joined the each program of Shizuoka STEM Junior Project, thus their belief system of creativities had more norms that were specific. Therefore, the author employed the other three undergraduate students to confirm the inter-rater reliability. As the result, the post-test also did not have enough coefficients among the raters. Thus, the post-test itself was probably not established well in the extent of TTCT. The combined results of scores by all raters computed and showed in Table 4-1.

As discussed above, those tasks were specific candidates to look at the application of divergent thinking. However, from this result, the consensus could not build on the graduate and undergraduate students of assessments. We need to know if experts of science score those responses of participants with enough consensuses, although that would be very difficult to conduct with the experts participation.

Finally, from this result, we need to consider the application of TTCT for assessing creativity in the context of science or STEM education. Because, even though the result of TTCT showed the improvement of creativity,

Result 2- Consensual Assessment Technique

First, the author computed Cronbach α to identify inter-rater reliabilities of the CAT for examining the possibilities of CAT for this task. The Table 4-3 & 4-4 shows the result of computing Cronbach α on the pre- and post-test results of CAT. CAT based on the consensus among experts in the domains and this study aimed to confirm the domain specificity and possibilities of consensus among experts and quasi-experts in science and the education, the examination arranged such rater groups as indicated in Table 4-3.

Table 4-3. The Difference of Cronbach α Among The Rater Groups in Pre-test

Rater Groups	Number of the Group Members	Cronbach α
Experts	5	0.32
Experts in Natural Sciences	3	0.42
Quasi-experts	7	0.72
Total	13	0.81

Enough Cronbach α (>.08) found only on the total score which included the all scores of those raters (Table 4-3.).

Table 4-4. The Difference of Cronbachα Among The Rater Groups in Post-test

Rater Groups	Number of the Group Members	Cronbachα
Experts	2	0.71
Quasi-Experts	8	0.60
Total	10	0.19

In the post-test, there was no enough Cronbach α found, although the group of experts had relatively high coefficient (Table4-4.). From those results CAT cannot work depends on the consensus of the experts, this time. Thus, all of those data bellow are just for your reference.

The result of pre- and post- CAT indicated on Table 4-5. – Table 4-8. The zero order correlation among experts in pre-test (Table 4-5.) shows the difference of correlations among those disciplines. The partial correlations on the result of pre-test (Table 4-6.) showed similar result, even though the attribution of gender and grade levels have been removed.

Table 4-5. Zero Order Correlation Among Experts and Quasi-Experts in Pre-test

	Experts					Quasi-experts						
	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.00	1.00										
3	0.00	0.07	1.00									
4	0.33	0.11	0.18	1.00								
5	-0.33	-0.21	0.40	0.08	1.00							
6	0.14	0.33	0.00	0.37	-0.07	1.00						
7	0.58 *	-0.10	0.25	0.14	-0.17	0.49 *	1.00					
8	0.00	0.48 *	-0.25	-0.02	0.04	0.18	0.02	1.00				
9	0.12	0.35	0.15	0.40	0.05	0.26	0.08	0.04	1.00			
10	0.29	0.19	0.26	-0.17	-0.11	0.49 *	0.66	0.15	0.01	1.00		
11	-0.17	0.32	0.66 **	0.04	0.38	0.42	0.26	0.05	0.21	0.54 *	1.00	
12	0.13	0.17	0.12	0.02	0.28	0.44	0.44	0.36	0.11	0.43	0.48	1.00

**p< .01, *p< .05 two tailed.

Table 4-6. Partial Correlation among Experts and Quasi-Experts in Pre-test

	Experts					Quasi-Experts						
	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.01	1.00										
3	-0.04	0.12	1.00									
4	0.40	0.23	0.15	1.00								
5	-0.29	-0.21	0.43	0.05	1.00							
6	0.09	0.52 *	-0.11	0.31	-0.05	1.00						
7	0.63 **	0.05	0.17	0.01	-0.15	0.27	1.00					
8	0.12	0.54 *	-0.23	-0.09	-0.04	0.32	0.21	1.00				
9	0.24	0.44	0.18	0.34	-0.03	0.32	0.15	-0.12	1.00			
10	0.23	0.28	0.21	-0.25	-0.07	0.40	0.60	0.31	0.08	1.00		
11	-0.29	0.46	0.64 **	-0.03	0.48 *	0.29	0.00	0.20	0.31	0.45	1.00	
12	0.05	0.20	0.08	0.05	0.37	0.42	0.40	0.55 *	0.23	0.37	0.43	1.00

**p< .01, *p< .05 two tailed.

Next, the Table 4-7. shows the result from the zero order correlations among experts and quasi-experts in the post-test of CAT.

Table 4-7. Zero Order Correlations among Experts and Quasi-Experts in Post-test

	Experts		Quasi-Experts						
	1	13	6	7	14	15	8	9	12
1	1.00								
13	0.62 **	1.00							
6	0.30	0.07	1.00						
7	0.39	0.53 *	0.12	1.00					
14	0.46	-0.03	0.59 **	0.30	1.00				
15	0.67 **	0.52 *	0.45	0.23	0.37	1.00			
8	0.32	0.11	0.06	0.34	0.36	0.03	1.00		
9	0.24	0.19	0.43	-0.13	-0.08	0.18	0.00	1.00	
12	0.12	0.04	0.11	-0.14	0.35	-0.21	0.18	0.39	1.00

**p < .01, *p < .05 two tailed.

The result of computing partial correlation among experts and quasi-experts on post-test appears on the Table 4-8.

Table 4-8. Partial Correlations Among Experts and Quasi-Experts in Post-test

	Experts		Quasi-Experts						
	1	13	6	7	14	15	8	9	12
1	1.00								
13	0.64 *	1.00							
6	0.28	0.09	1.00						
7	0.39	0.61 *	0.12	1.00					
14	0.58 *	0.12	0.47	0.27	1.00				
15	0.67 *	0.53	0.46	0.24	0.45	1.00			
8	0.29	0.15	-0.09	0.31	0.23	0.00	1.00		
9	0.24	0.19	0.49	-0.14	0.00	0.18	0.00	1.00	
12	0.07	0.05	-0.22	-0.19	0.03	-0.31	0.03	0.47	1.00

** p < .01, * p < .05 two tailed.

Discussion 2- Consensual Assessment Technique

First, if you see the test of inter-rater reliabilities, the coefficients are usually used to confirm the reliability. On CAT, the coefficient works to see the consensus among experts. As Table 4-3 and 4-4 shows, the author cannot find enough coefficients ($\alpha > .80$) among experts, experts in natural sciences, and quasi-experts. Only on total score ($\alpha = .81$) which includes all of judges had enough coefficients. However, the properties were not examined enough to identify their characteristics. Although the assessments by experts did not have enough coefficients, the author computed correlations to identify the difference of their assessments.

Particularly from the result of pre-test, the assessment by the experts from different domain of science did not have correlations and the decorrelation analysis showed that some of the assessments by quasi-experts had correlations with experts. However, the major or study experiences among those members did not have any apparent relation. These results were supported, even if the partial correlations were computed.

In the post-test, in turn, the assessment by experts had correlations and the result was supported by the decorrelation analysis and the partial correlation, either. As the former teachers also had correlations with those experts, the result probably, be affected by the experience as a teacher. However, this view does not apply to all of the examples.

As research hypothesis stated, the domain specificity on the assessments by experts were suggested. However, the possibility of assessments by the quasi-experts still had doubts. Because, the assessments by the quasi-experts did not have correlations in many case on this results.

Result 3- Cascade of Inquiries (Practices)

This result 3 shows the students cascade of practices and the differences within each group. First, the Table 4-7. shows trace of cascade which each participant follows. The numbers indicate the eight practices as listed in the Next Generation Science Standards (NGSS Achieve, 2013) Appendix F and Table 2-4.

Table 4-9. Trace of Cascades Which The Participants Follow

Group	Grade	Participants \ Dates	5/29	6/11	6/18	7/9	9/3	9/17	10/15	10/29	11/12
A	7	1	3-4-2	2	1	2		3	3,2		
	10	2	3	3			3	3			3,6,8
	7	3	1		1	3		2	4	1	6
	9	4	8	8	2	3	3	3,4	3		
	7	5	3	3	3		2	3	2	3	7
B	8	6	8			3					
	9	7	1	8	3	3		3			
	8	8	3		2	3	3,4	3,4	3,6	3,6	4
C	6	9	3		2		6	6	3	3	4
	6	10	3	1	2		2	3		3	3,4
	8	11	1-3-2			2	3	3	3,7	3-1,2	2
	10	12	2		2					3	2
D	8	13	2	4	4		2,3	2,3		2	4
	7	14	3	3	2		2	4	4	2	4
	7	15	3		4,6,7	1				2	
	7	16	3	4	4	4	3			2	4
E	9	18	3		8	3				3	8
	8	19	3	3	2	2	2	2	2	5	6
	9	20	3				3	1		4	
	6	21	3	7	4	1	4			4	

Numbers connected by "–"means the prediction of cascades for next several times.
Numbers divided by the "," means prediction of cascade for next one time.
The empty tables mean the absence of the participant.

The Figures 4-1 - 4-5 show the differences among cascades within each group. The x-axis from 0 to 8 on the graph indicates the each programs from 5/29 -11/12.

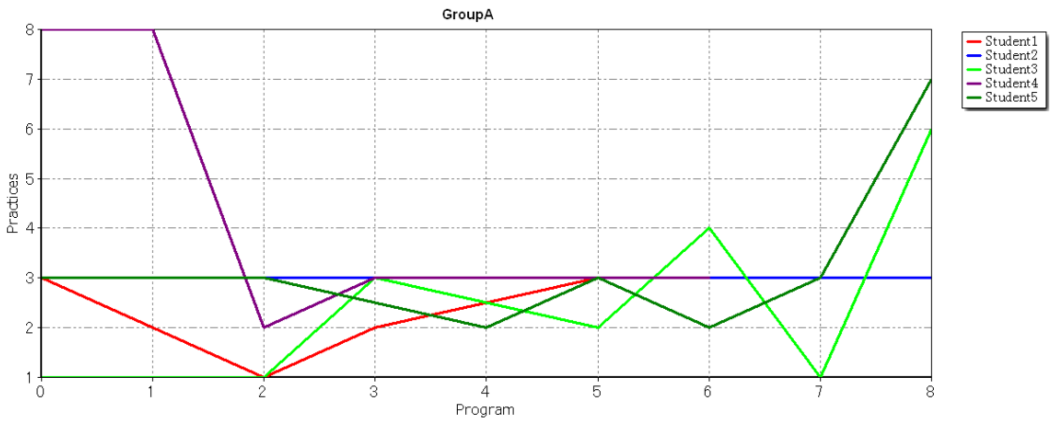

Figure 4-1. Difference of Cascades in Group A

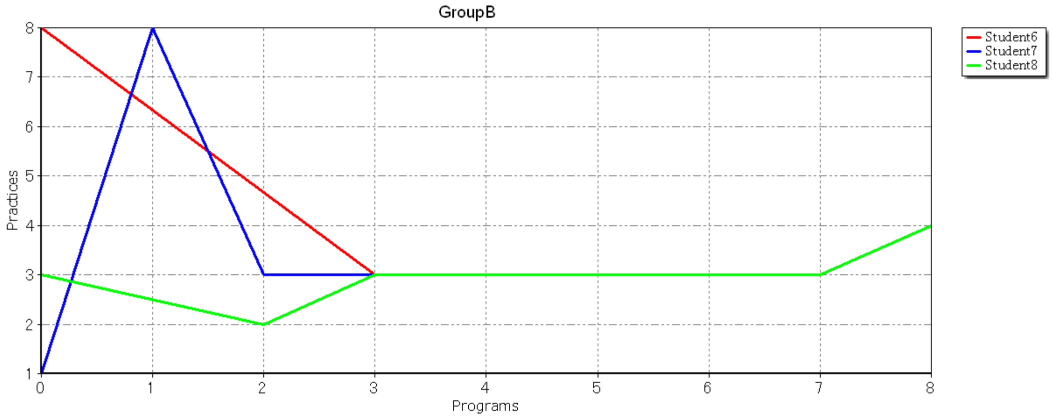

Figure 4-2. Difference of Cascades in Group B

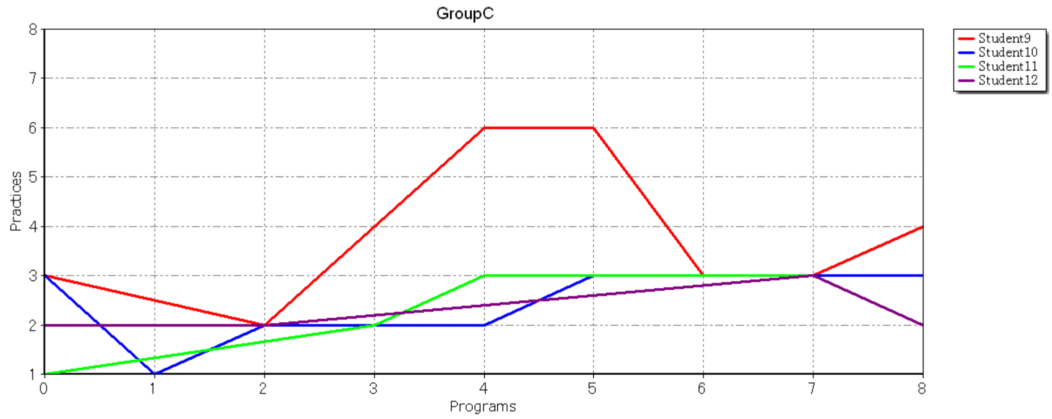

Figure 4-3. Difference of Cascades in Group C

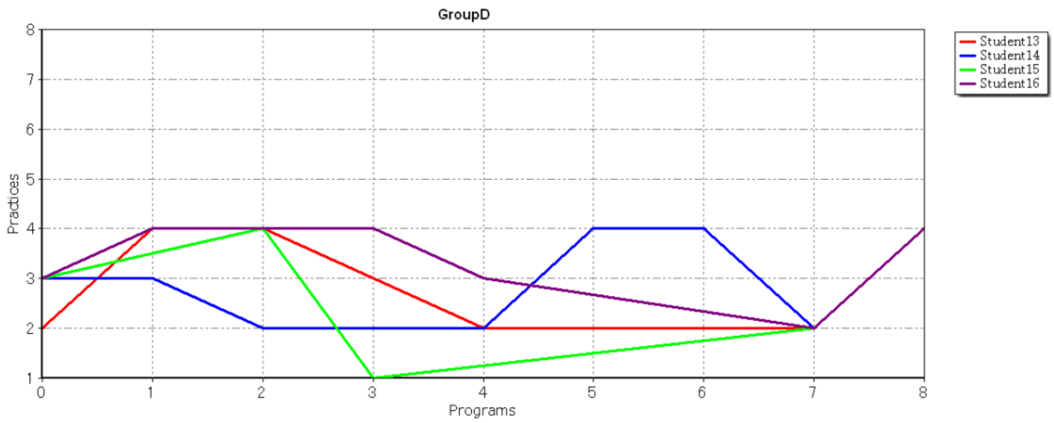

Figure 4-4. Difference of Cascades in Group D

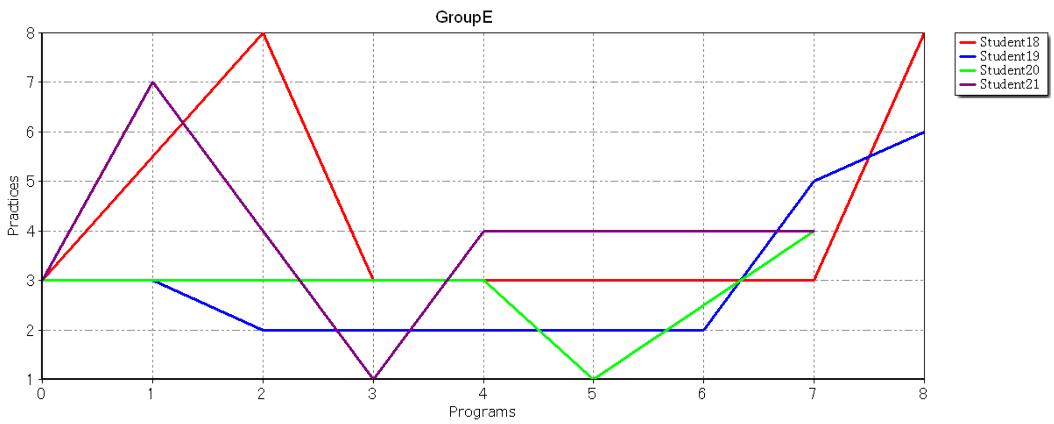

Figure 4-5. Difference of Cascades in Group E

Discussion 3- Cascade of Inquiries (Practices)

This analysis showed that the difference of cascade of inquiries (practices) among the participants and the groups. As the result, one of the hypotheses of this study was confirmed.

Although the program provided as group inquiries in this study, the participants followed different cascades within each group. This is evident that although the participants had already had enough communication prior to the program from 2013 through 2015, they did not have consensus to arrange their way to solve the questions or problems.

As Discussion 1 argued, most of their cascades go around Practice #1 to #3, among #1 asking questions & defining problems, #2 developing & using models, and #3 planning & carrying out investigations. This fact might have impacts on the quantitative data and qualitative descriptions on the application of the divergent thinking (see Result & Discussion 1 on this chapter and the quantitative analyses on Chapter V).

Some of the participants like Student 4, 6, 7, 18, 19 took Practices 8 relatively early stage of the inquiries (practices) and they are all eighth or ninth grade students. It is a suggestion that the higher grade students like them felt the necessity of communication of information or ideas in the development of their group inquiries.

From this investigation, you can find some possible effects on the cascades of inquiries (practices). In this time, they were the consensus on deciding cascades and the communication of their information or ideas. As Gibbons (1994) predicted the communication is very important in the transdisciplinary learning environment.

Chapter V: Qualitative Part: Explanatory Approach

In this chapter V, the result of qualitative analyses will be shown. As the qualitative part of this mixed methods approach, the author analyzed the participants' reflections on the application of creative thinking on to their group inquiries (practices) and their own independent inquiries (practices).

Result 3- Application of Creative Thinking on Participants' Group Inquiries

This result 3 arranges the analysis on the application on the group inquiries (practices). In Table 5-1, the categories indicate the number of eight practices of Next Generation Science Standards (NGSS; NGSS Achieve, 2013).

Table 5-1. Participants' Descriptions Where They Apply Creative Thinking Through Group Inquiries

Categories	Sub-categories	Represented Descriptions
1	Asking questions or deciding problems for the group inquiries	When we talked about problems for our group The situation when we think our theme The viewpoint I thought to make the study theme more interesting To decide the purpose
	Specific topics for the group themes	I thought how we could make the power of rocket enough to fly. When I wrote, I wanted to talk with animals, especially.
	Defining problem in future activities	We considered the future problem of us in this team. When I think up the problem for our group.
	Reflection on the question	I thought weather the root question was necessary to solve the problem.
3	Method development	When I thought about the method. When I thought about the sequences of experiment. When I thought about how I can measure the pressure.
	Gathering information to planning the investigations	When I investigated the basic knowledge. When I expand the knowledge about photosynthesis. What I learned from a video.
	Brainstorming to decide the variables in the investigations	The difference of human thinking and animal Thought about what was stain The possible patterns of solutions
	Making the list of materials	Listing up the necessary Thought about materials for experiment Tools
		To decide the financial plan To think up what was not enough for the plan
3	Needs identification	Why we will do this study Who need this study Why they need this study. There are many ideas. When we thought the needs.

Table 5-1. Continued

3	Preparation thought	When we though what we do prior to the experiment.
4	Interpretation of the result	I thought about why curry did not spread on the cloths, although soy source or source did.
	Implications and interpretations	I thought about implications after this and went back to the interpretations.
8	Discussions within groups	When I talked within separated groups
	Presentation of the researches	When I made individual presentation. The individual presentation.
	Listening on the presentations by other groups	I thought that was there any possible applications from the presentations of others. To understand the presentations of others.
X	Limitation by critical thinking	I just only think critically, today.
	Self-reflection	When I arranged my idea.
	Seeking minor solutions	When my Arduino program did not work well. (When I seek its solutions)

Discussion 4-
Application of Creative Thinking
on Group Inquiries (Practices) - Candidate Tasks

From the result of qualitative analysis on the application of creative thinking on group inquiries, there were such tasks that can apply to the extent of eight practices. In addition to the extent, there were few tasks where they could apply creative thinking during group inquiries (practices) outside of the categories.

In category #3, you can find sub-category "Gathering information to planning the investigations." It assumed that this sub-category could be included in the category #8 as well. However, these descriptions actually aimed to planning their investigations. Thus, it had taken the place in category #3.

In this time, practice #2, 5, 6, and 7 did not have any descriptions.

From the few descriptions which could not include in the extent of eight practices, it had revealed that the participants sometimes only thought on critical thinking style, thought creatively only on their own, and thought their solution on a minor problem which has occurred during their inquiries. It was not a total engineering problem, but a minor problem the activities potentially had.

Result 5- Application of Creative Thinking on Participants' Independent Inquiries (Practices)

In this result 5 the application of creative thinking to the participants' own independent inquiries. The categories also indicate the number of eight practices as appear on the NGSS.

Table 5-2. Participants' Descriptions Where They Apply Creative Thinking to their own Inquiries

Categories	Sub-categories	Represented Descriptions
1	Asking questions or writing problems	Decision of my question or problem Listing up the problems or questions Seeking questions or problems from my previous studies
		Thinking up related problem to my problem that preventing stalling angle.
	Asking what would be asked	What is what I want to reveal What I want to know Making figures to arrange the purposes.
	Deciding the themes	Deciding theme Thinking my theme
	Deciding purposes	Thinking purpose Deciding purpose Purpose of experiment
	Thinking about rationales	Thinking about why I conduct this study Incentive I started this study Think about the needs of my study
2	Predicting	When I make prediction
	Making hypothesis	I think creatively when I decide the hypothesis based on prior experiences Listing up possible hypothesis
		I will think how cockroach wing repel something
3	Thinking about methods	Method of experiment Method to demonstrate the hypothesis Planning of the study Deciding the method Thinking how I can start from the theme Thinking next method of experiment Conducting experiment using familiar stuffs How to conduct the experiment of electromagnet.
	Development of tools for experiment	When I think how to develop the tools for experiment and the time when I develop them.
	Making the list of materials	When I decide the financial plan. Listing up materials before I decide to buy. When I decide where I go for the investigation.
3	Making the list of materials (continued)	Thinking about what I need. Preparation to succeed the experiment and to get accurate data
	Planning for the next experiments	Planning for the future Thinking about next experiments
	Deciding work environment	Decide the place for experiment depends on its safety or what I want to know

Table 5-2. Continued

3	Specific application to the participants own inquires	improvement	Way to improve the magnetic force When I think the way to improve the electromagnet When I thought the way to proceed the train When I think the way of covering the flower. Way to remove the armyworm When I think how to utilize the Karman's vortex. How to decrease the Karman's Vortex.
		efficiency	When I think how to conduct the experiment more efficiently.
		deficiency	What is the disadvantage when I use acid?
		how to use	How to use acid and alkali?
		how to measure	The way to measure the magnetic force. I listed several ways to measure the size of the leaves. Tinkering the experiment to conduct accurately.
		how to make	When I decide how to make soap. When I think how to make the crystals.
		how to decide the variance	The necessity of cyclic acid. What is the benefit when I use acid? When I seek strong acid. When I decided other plants to compare to the Zuina. Which sugar would be compared in the experiment? When I decide the soap. When I decide a fungus cultured on gelatin. Selection of pigment.
4	How to interpret the data	Way of interpretation. When I make the interpretation. What I can think from the result. I think what I do lead classification or regularities.	
	Analysis of cause and effect	When I think the cause of the result When I interpret the data, I think the possible causes.	
	Specific application to the participants own inquires	Seeking what is spoiling the power around the wing.	
	Looking forward	I thought that I needed to think creatively when I finished the previous experiment.	
	Looking forward	I thought that I needed to think creatively when I finished the previous experiment.	
5	Way to arrange the data mathematically	Way to decide the tables or graphs. The way of arrangement such values has many methods.	
	explaining what I do and find	When I explain what I did previously. When I explain the result.	
6	Designing solutions	When I think the solutions. When the solution change through variety of viewpoint	
	Specific application by the participants	The condition how to increase the angle of attack When my instrument does not work well. When Arduino did not work well in my inquiry. It was also happen I made it with analog circuit.	

Table 5-2. Continued

6	Communication with audience	When I had the first presentation and get opinion from the audience.
7	Writing the proposal	When I think my research proposal that will be, appear on the application of a grant. When I think how to write an understandable sentences. How to write a paper. When I wrote a report. When I thought the construction of a paper.
8	Obtaining basic knowledge	When I think what I need to know first.
	Communications by presenting the researches	How to make a power point slide. How to make the effective slides. How to explain simply and easy to understand what I want to say.

Discussion 5- Application of Creative Thinking on Participants' Independent Inquiries (Practices)

In this result, you can also find the application of the creative thinking among the participants' independent inquiries (practices).

As same as the result 4, the descriptions were included in the extent of eight practices. More candidate tasks could be the application and training point of creative thinking during the STEM independent inquiries.

Moreover, there were the evidence where they applied those creative thinking into their own inquiries (see the categories "Specific application to the participants own inquires"). Thus, those tasks selectively coded and they applied creative thinking should be focused and could be the tasks to help their application of task specific creativities.

However, those tasks very related to participants own inquiries. Thus, the application might depend on their familiarities on such specific points. If so, the application or transfer of divergent thinking skills must align to their learning on the subjects. In the other words, experts must have specific way of applications.

Chapter VI: Conclusion, Implications, & Future Research

This chapter arranges the discussions from the data of mixed methods analyses and provides meaningful discussion for the further researches. Those analyses were intended to answer such research questions as:

(1) How task specific approaches improved students' creativity in the extent of Torrance Tests of Creative Thinking that had been applied to the area of integrative Science Educations or its STS approaches?
(2) Were the students' creativity assessed differently in each area of STEM?
(3) When students engaged in the STEM independent practices, how did they follow the cascades of eight practices? Were they different within/among groups?
(4) What kinds of potential creative tasks did students show during their own cascade of inquiries (practices)?
(5) If students realized the task specific divergent thinking, where & when did they apply it to their own inquiries (practices)?

Conclusion

Quantitative Analyses

TTCT

In the extent of the application of Torrance test of creative thinking (TTCT), the participants' creativity was improved through task specific practices in the independent STEM inquiries (practices). In the past sense of TTCT, the result showed the improvement of creativity that meant the applications of divergent thinking. However, in the revised sense of creativity, those tasks could see the possible divergent thinking tasks in the STEM inquiries (practices). Thus, in the future research on creativities in the STEM (science) education, those tasks should be trained and examined, separately and intendedly and **the results should not be discussed as a total creativity performance**.

CAT

From the result of consensual assessment technique (CAT), there was no correlation among experts in the domain of Science Education, Biology, and Earth Science. More specifically, their major were Geology, Chemistry, Ecology, Developmental Biology, and Space Science. Even if they majored in the same domain of science (e.g. biology), the assessment by those judges are different each other, as predicted from the literature reviews (Chapter 2).

If the judges involved the quasi-experts that were recommended in the past several studies (Kaufman, Bear, Cole, 2009), several judges had correlations under 5 % level of significance. However, the correlations cannot find among the quasi-experts. Moreover, although some correlation can find between experts and quasi-experts, the author cannot find any suggestion to support those correlation. For example, their majors and ages are different each other.

Cascades of inquiries (practices)

The cascades of inquiries (practices) in this set of group inquiries were different each other among those participants. Even though they worked in the same groups, the traces of cascades of the participants were different within those groups. Therefore, it was confirmed, even in such group inquiries (practices); the students followed the different cascades that could definitely be called heuristics.

Qualitative Analysis

Application of divergent thinking- Candidate tasks in-group setting

Although the author expected that the participants would apply the creative thinking to many different points and indeed, they applied it to the different context, the differences of application did not appear enough on those descriptions. Rather, it seemed that the participants applied divergent thinking to the extent of eight practices. Still those categories of application to the extent of eight practices could be a candidate tasks to nurture their creative thinking during such independent inquiries. Furthermore, they must support the students' creative inquiries in the school settings by explicitly tell them where they can apply.

Transfer of creative thinking to their own inquires (practices)

On the other hand, the application to their own inquiries had rich variety than what they described for the group settings. Particularly, in the categories #3 planning and carrying out investigation has much descriptions how the participants applied divergent thinking to their own inquiries.

With compare to the group setting, those participants are more familiar with their own inquires than the group inquiries. Thus, the total perspectives (meta-cognition) for their own inquiries may effect on this point. If they can overview the group inquiries, similar enrichment would be happen.

Total Conclusion from Quantitative and Qualitative Analyses

In past, the Torrance test of creative thinking has been used in the domain of science education. However, if we take this as revised meaning of divergent thinking, the each task for TTCT also means the scales for measuring the task specific creativities. Indeed, the three tasks that utilized in this study had been applied to the *Iowa Assessment Package* (McComas & Yager, 1988). Even though they used these tasks as the instruments to assess creativity domain among the *Six Domains in Science Education*, the way of use the Torrance test of creative thinking and the relationships of each tasks should be examined. Because, Torrance did not intend to apply specific results to the total mean of creativity (Bear, 1993).

In addition, CAT could not show the correlation among experts in science and its education domain in this case. Thus, this assessment task, research presentation, could not use to assess the participants' competencies of creativity in this case. As prior studies suggested, the quasi-experts were the candidates for the assessing committee (Kaufman, Bear, Cole, 2009). However, the result of this study suggested that the assessment by quasi-experts also did not have consensus based on their coefficient α. One possibility is that experience as teachers in school would have the effect on the correlations among their assessment.

Moreover, the cascade of inquiries which the participants follow were different each other, even in the same group. Therefore, possibilities of application or training for their inquiries must have occurred in different time and place where they made. In this year of Shizuoka STEM Junior Project, the participants' activities did not continue to the phase making conclusions. It also had possibilities to effect on the result of Torrance test of creative thinking and it must have effected on the effect size and the power (1-β). However, even if its effect would be adjusted, the relatively lower score of inter-rater reliabilities (Cronbach α) could not be explained. The task in post-test should be rewrite for this point.

In both qualitative settings, the participant applied the divergent thinking to the extent of eight practices. However, if their cascades of inquiries (practices) follow the different lines, the applications occur different moments and places where the participants try.

Implication

This section explains the implications of this study related to the research of creativities in science and/or STEM education and has possibilities to the other domains of researches in education and their implementations. First, as a 21ts century skills, those studies need to consider the domain specificity, furthermore task specificity of creativities. Second, to assess the creativities during science and/or STEM inquiries (practices), those tasks that had found in the qualitative analyses should be elaborated and adopted to implementations in many contexts. Third, considering the Learning Progressions (LPs), the tasks should be ground up from the students' work in STEM integrated learning environment (SILE).

The 21st century skills need to be considered the domain specificity, furthermore task specificity. It had been suggested that not only creativities, but also some skills called 21st century skills had domain specificity (Koenig, 2011). If so, we need to confirm the versatilities of 21st century skills and its applications to the implementations in schools. As this study showed the difference of assessment on the product of STEM inquiries' (practices') creativity, the critical thinking skills (Kuncel, 2011), or the other related skills also may have such characteristics. In addition, we need to consider the differences between performances and competences. In the other words, the availabilities (performances) and product (competences) have differences on its assessment (Bear, 1993). Coupling with the Project-based Learning, we need to consider the characteristics of those skills (competences) and their assessments. Because, their cascades of practices in PBL might have difference, even if they engage inquires in the group setting.

On this point, we can also consider the type of cascades which may valuable for the students-centered approaches. Although this study assumed that there are no one fit all type of cascade, the cascade of learning also might effect on the students' self-efficacy and their confident. Thus, the relation among cascade of inquiries (practices), meta-cognition, and students' self-efficacy should be considered and be confirmed throughout the independent (group) inquiries (practices) of the project.

For assessing the creativities in STEM inquiries (practices) thus, the tasks should be elaborated and adopted to implementations in many contexts. This study can be seen as a single case study. Therefore, the tasks and its categories are not enough to describe the all of their applications to divert students of divert independent inquiries (practices). Many of continual studies should be done and need to identify the tasks which are appropriate for the contexts.

In addition, it is important to note that the tasks should be ground up from the students work in SILE by considering the LPs. The reason why the author started independent inquiry has a basis and two implications. As the basis, those educational researches should be ground on the students' work and evidenced by them. On this basis, there are two implications onto research and practices. First, the standard based assessment should be effected by the ground up suggestions. Although we cannot ignore the historical properties of education, the students change over time and the assessment also need to be considered accordingly. Second, the implementations need to encompass the fallibilities of knowledge and the standards. Thus, as creative environment suggest judges should be postponed and be taught appropriately. Because, the judgement is a component of creativity.

In conclusion, to think about 21st century skills and its application for the school education, the author recommends considering their domain specificities and possibilities of their task specificities. Although the 21st century skills sometimes have taken as competences that transferable, some of those skills had suggested that the assessments indicate domain specificities (Koenig, 2011). Therefore, their nurturing in schools should mutually be exclusive and correctively be exhaustive in all subjects on the curriculum and their classes. The researches supporting the implementation also need to identify the tasks that can be the pints of instructions. However, it is important to note that the tasks sometimes need to be shown by the students who are learning on the 21st century skills as LPs researches suggests (Gotwals & Alonzo, 2012).

Recommendations for Future Research

This section states the recommendations for the future research. However, most of them need to be completed with the Shizuoka STEM Junior project or related programs. First, it is about the redevelopment of the creative problem solving (CPS) program with task specific approaches. Second, related theoretical framework should be arranged and shared among the staffs and educators. Third, the instrumentation for both quantitative and qualitative analyses needs elaboration in terms of usabilities on the e-learning system.

In the Embodiment part of conjecture map, we have applied independent inquiries (practices) this time. It was a sequenced creative problem-solving program in 2014. However, it was also confirmed that the participants do not follow the same sequences and it takes more time to complete a set of inquiries in groups. Thus, the redevelopment and re-embodiment of CPS program must be needed.

Next, as of the theoretical frameworks has been discussed in the researchers side, the staffs sometimes do not share such effect of theoretical conjectures as constructivism or fallibilism on the practical conjectures.

References

AAAS. (1991). PROLOGUE: DESIGN IN GENERAL. In American Association for the Advancement of Science (Ed.), *Designs for Science Litearacy* (p. 15). Oxford, New York: Oxford University Press.

Adler, M. (1982). The Paideia proposal: Rediscovering the essence of education. In A. Canestrari & B. Marlowe (Eds.), *Educational foundations: An anthology of critical readings* (Third Edit, pp. 141–149). SAGE Publications, Inc.

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology*, *43*(5), 997–1013. http://doi.org/10.1037/0022-3514.43.5.997

Appleton, J. V, & King, L. (1997). Constructivism: a naturalistic methodology for nursing inquiry. *ANS. Advances in Nursing Science*, *20*(2), 13–22.

Baer, J., & McKool, S. S. (2009). Assessing creativity using the consensual assessment. *Handbook of Research on Assessment Technologies, Methods, and Applications in Higher Education*, 1–13. http://doi.org/10.4018/978-1-60566-667-9.ch004

Bailey, R. (1978). *Disciplined creativity for engineers* (2nd ed.). Ann Arbor: Ann Arbor Science Publishers, Inc.

Barab, S. (2014). Design-Based Research: A Methodological Toolkit for Engineering Change. In R. K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 151–170). New York: Cambridge University Press.

Barab, S., & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*, *13*(1), 1–14. http://doi.org/10.1207/s15327809jls1301_1

Bear, J. (1993). *Creativity and Divergent Thinking: Task-Specific Approach*. Hillsdale: Lawrence Erlbaum Associates, Inc.

Beatty, A. (2011). *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. Social Sciences*.

Brown, A. L. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *Journal of the Learning Sciences*, *2*(2), 141–178. http://doi.org/10.1207/s15327809jls0202_2

Bruner, J. (1961). the Act of Discovery. *Harvard Education Review*, *31*(1), 21–32.

Bybee, R. W. (2011). Scientific and engineering practices in K–12 classrooms. *Science Teacher*, *78*(December), 34–40.

Bybee, R. W. (2013). *The case for STEM education challenges and opportunities*. Arlington, Virginia: National Science Teachers Association.

Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *Studies in Science Education*, *44*(1), 1–39. http://doi.org/10.1080/03057260701828101

Clark, E. (2005). Designing and implementing an integrated curriculum: A Post Script. Retrieved December 16, 2014, from https://great-ideas.org/ClarkPS.pdf

Collins, A. (1992). Toward a design science of education. *New Directions in Educational Technology*, 15–22. http://doi.org/citeulike-article-id:4545332

Committee on How People Learn. (2005). *How Students Learn*. Washington D.C.

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Washington D.C.: SAGE Publications, Inc. http://doi.org/10.1111/j.1753-6405.2007.00096.x

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297–334. http://doi.org/10.1007/BF02310555

D'Ambrosio, U., Black, P., El-Tom, M., Matthews, M., Nebres, B., & Nemetz, T. (1992). Summer symposium on educating for citizenship in the 21st century. In *Science , Mathematics , Engineering , and Technology Education for the 21st century* (p. 73). Washington D.C.: National Science Foundation Directorate for Education and Human Resources Division of Research, Evaluation and Dissemination.

DeBoer, G. (2006). History of the Science Standards Movement in the United States. *The Impact of State and National Standards on K-12 Science Teaching*.

Dewey, J. (1899). *The School and Society*. Chicago: The University of Chicago Press.

Dewey, J. (1938). *Logic: The theory of inquiry. Holt, Rinehart and Winston* (1960th ed.). New York: Holt, Rinehart and Winston, INC.

Ernest, P. (1995). Preface. In P. Ernest (Ed.), *Radical Constructivism: A Way of Knowing and Learning* (pp. xi–xii). New York: RoutledgeFalmer.

Fensham, P. J. (2009). Real world contexts in PISA science: Implications for context-based science education. *Journal of Research in Science Teaching*, *46*(8), 884–896. http://doi.org/10.1002/tea.20334

Fogarty, R. (1991). Ten ways to integrate curriculum. *Educational Leadership*, *49*(2), 61–65.

Glasersfeld. (1995). *Radical Constructivism: A Way of Knowing and Learning*. (P. Ernest, Ed.). New York: RoutledgeFalmer.

Guilford, J. P. (1956). The structure of intellect. *Psychological Bulletin*, *53*(4), 267–293. http://doi.org/10.1037/h0040755

Han, S., Capraro, R., & Capraro, M. M. (2014). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: the impact of student factors on achievement. *International Journal of Science and Mathematics Education*, *13*(5), 1089–1113. http://doi.org/10.1007/s10763-014-9526-0

Hantz, H. D. (1952). The Nature of Concepts, Their Inter-Relation and Role in Social Structure. In *Rural Sociology* (pp. 73–74).

Hennessey, B. A., Amabile, T. M., & Mueller, J. S. (2011). Consensual Assessment. In M. A. Runco & S. Pritzker (Eds.), *Encyclopedia of Creativity* (2nd ed., Vol. 1, pp. 253–260). San Diego: Elsevier Inc. http://doi.org/10.1016/B978-0-12-375038-9.00046-7

House of Representative. STEM Education Act of 2015, Pub. L. No. 1861 (2015). the United States of America: 42 U.S.C.

James, W. (1907). *Pragmatism: A New Name for Some Old Ways of Thinking*. London: Longmans, Green, and Co.

Kain, D. L. (2003). *Problem-Based Learning for Teachers, Grades 6-12*. New York: Pearson Education, Inc.

Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects. National Academy of Engineering and National Research Council of the National Academies.* National Academies Press.

Kaufman, J. C., Lee, J., Baer, J., & Lee, S. (2007). Captions, consistency, creativity, and the consensual assessment technique: New evidence of reliability. *Thinking Skills and Creativity*, *2*(2), 96–106.

http://doi.org/10.1016/j.tsc.2007.04.002

Kilpatrick, W. H. (1918). The project method: the use of the purposeful act in the educative process. *Teachers College Record*, *16*(4), 319–335.

Koenig, J. A. (2011). *Assessing 21st Century Skills: Summary of a Workshop*. Washington D.C.: National Academies Press.

Kumano, Y. (1993). *The Effects of STS Instruction in Japan Compared to Results Reported in the US*. University of Iowa.

Laboy-Rush, D. (2011). *Integrated STEM Education through Project-Based Learning. Learning. com*.

Lai, E. R., & Viering, M. (2012). *Assessing 21 st Century Skills : Integrating Research Findings National Council on Measurement in Education*. Vancouver, B.C.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). *A Theory of.Instruction: Using the Learning Cycle.To Teach Science Concepts and Thinking Skills*. *NARST Monograph* (Vol. 1). Cincinnati: National Association for Research in Science Teaching.

Lobato, J. (2006). Alternative perspectives on the transfer of learning : History, issues , and challenges for future research. *The Journal of the Learning Sciences*, *15*(4), 431–449.

Ministry of Education Culture Sports Science and Technology. (2008). Course of study. Retrieved from http://www.mext.go.jp/english/elsec/1303755.htm

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. a, Smith, K. a, & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research*, *4*(1), 1–13. http://doi.org/10.7771/2157-9288.1069

National Research Council. (2000). *How people learn: Mind, brain, experience and school, expanded edition. National Academies Press*. Washington, DC.

National Science and Technology Council. Charter of the Committee on Science, Technology, Engineering, and Mathematics (STEM) Education (2011).

National Society for the Study of Education. (1947). Issues in the teaching of science. In *46th Year Book* (pp. 41–59). Wasington D.C.

NGSS Lead States. (2013). *Next Generation Science Standards: For states,* *by states*. (Achieve, Ed.). Washington, DC: The National Academies Press.

Northrop, F., & Margenau, H. (1950). The nature of concepts, their interrelation and role in social structure. In *Proceedings Stillwater Conference June 6-9* (p. 139). Stillwater, Oklahoma: the Foundation for Integrated Education, Inc.

OECD. (2014). *PISA 2012 Results: Creative Problem Solving: Students' Skills In Tackling Real-Life Problems* (PISA) (Vol. V). OECD Publishing.

Olson, S., & Labov, J. (2014). *STEM learning is everywhere: Summary of a convocation on building learning systems*. Washington, DC: The National Academies Press.

Osborn, A. F. (1963). *Applied Imagination: Principles and Procedures of Creative Problem Solving* (3rd revise). NewYork: Scribner.

Phenix, P. H. (1962). Discipline as Curriculum Content. In *Curriculum Crossroad* (pp. 56–65). New York: Teachers College, Columbia University.

Pierce, C. S. (1931). *Collected Papers of Charls Sanders Pierce*. (C. Harthome & WeissPaul, Eds.). Cambridge, Massachusetts: Harvard University Press.

Piirto, J. (2011). *Creativity for 21st Century Skills*. SENSE PUBLISHERS.

Plucker, J. A., & Runco, M. A. (1998). The death of creativity measurement has been greatly: Current issues, recent advances, and future directions in creativity assessment. *Roeper Review*, *21*(1), 36–39. http://doi.org/10.1080/02783199809553924

Poincaré, H. (1908). *Science et méthode*. New York: Dover Publications.

Pratt, H. (2013). *The NSTA Reader's Guide to A Framework for K–12 Science Education Practices, Crosscutting Concepts, and Core Ideas* (2nd ed.). Arlington, Virginia: NSTA press.

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future: Executive report*. (President's Council of Advisors on Science and Technology, Ed.). Executive Office of the President.

President's Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the* *president. Executive Office of the President*.

Roehrig, G., Moore, T., Wang, H., & Park, M. (2012). Is adding the E enough? Investigating the impact of K‐12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.

Runco, M. A. (1994). *Problem Finding, Problem Solving, and Creativity*. (M. A. Runco, Ed.). Norwood, New Jersey: Ablex Publishing Corporation.

Russell, D. H. (1956). Problem Solving. In *Children's'Thinking* (pp. 251–280). Boston, MA: Ginn and company.

Saito, T., Anwari, I., Mutakinati, L., & Kumano, Y. (2016). A look at relationships (Part I): Supporting theories of STEM integrated learning environment in a classroom - A historical approach. *K-12 STEM Education*, *2*(2), 51–61.

Saito, T., Gunji, Y., & Kumano, Y. (2015). The Problem about Technology in STEM Education: Some Findings from Action Research on the Professional Development & Integrated STEM Lessons in Informal Fields. *K-12 STEM Education*, *1*(2), 85–100.

Saito, T., & Kumano, Y. (2015a). A study about integrated activities and its assessments in STEM classes. In *Shizuoka STEM Junior Project 2014-2015, A Report for the Future Scientist Program by JST* (pp. 32–50). Shizuoka, Japan.

Saito, T., & Kumano, Y. (2015b). *A study about STEM camp implementation which based on a transdisciplinary issues and assessment of the solutions developed by the participants*. Shizuoka, Japan.

Saito, T., & Kumano, Y. (2015c). *A Study about the Students ' Learning and Its Reflections Through STEM Tour to Institutes and Corporations*. Shiuoka, Japan.

Saito, T., & Kumano, Y. (2015d). *An Action Research about Independent Inquiry based on a Creative Problem Solving Program in the STEM Classes and an Online Program*. Shiuoka, Japan.

Saito, T., & Kumano, Y. (2016). A Study on the Scientific Research in the Study of the Science Education. *Report for Japan Society for Science Education*, *30*(9), 51–56.

Saito, T., Mutakinati, L., Anwari, I., Suwaruma, I. R., Shido, M., & Kumano, Y. (n.d.). A look at relationships (Part II): A mixed methods analysis in a case of STEM integrated learning environment -Qualitative analysis and teachers' assesment-. *K-12 STEM Education*.

Saito, T., Okumura, J., & Kumano, Y. (2014). The STEM education research in Japan and its prospective. In *The Newsletter of the East-Asian Association for Science Education* (Vol. 7, pp. 5–10).

Sanders, M. (2009). Integrative STEM Education: Primer. *The Technology Teacher*, *December/J*, 20–26.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(August 2014), 18–36. http://doi.org/10.1080/10508406.2013.778204

Shirouzu, H. (2012). Knowledge transfer in cognitive science and learning sciences. *Journal of the Japanese Society for Artificial Intelligence*, *27*(4), 347–358.

Stuart, L., & Dahm, E. (1999). *21St Century Skills for 21St Century Jobs*. the U.S. Department of Commerce, U.S. Department of Education, U.S. Department of Labor, National Institute of Literacy, and the Small Business Administration.

Towne, L., & Shavelson, R. (2002). *Scientific research in education*. (Committee on Scientific Principles for Education Research, Ed.). National Academies Press.

Umene, S. (1977). *Collected Writings of Satoru Umene 6*. Tokyo, Japan: Meijitosho Shuppan Corporation.

Vasquez, J. A., Sneider, C., & Comer, M. (2013). *STEM Lesson Essentials, Grades 3-8: Integrating Science, Technology, Engineering, and Mathematics*. (K. Bryant, Ed.). Washington, D.C.: Heinemann.

Wallas, G. (1926). *Art of Thought*. (J. Cape, Ed.). London: Harcourt Brace.

Yager, R. E. (1986). Searching for excellence. *Journal of Research in Science Teaching*, *23*(3), 209–217.

Yager, R. E., & Tamir, P. (1993). STS approach: Reasons, intentions, accomplishments, and outcomes. *Science Education*, *77*(6), 637–658.

Appendix A- Directions for Experts on CAT

先生方へ

今日は静岡 STEM ジュニアプロジェクトの開講式にご参加くださいまして、ありがとうございます。

今回、ステージ２・３に参加する児童・生徒は、これまで静岡科学館る・く・るでの科学教室等に参加するなど、各自で研究を進めてきた子どもたちです。今日は、第一回目の活動として、彼らがこれまでに進めてきた自由研究の発表を行います。

そこで、先生方の専門家としての観点から、直感的に彼らの研究の創造性について１～５の５段階で評価をしてください(５が最高値とします)。また、この評価とは別に、各自の自由研究についてのアドバイス、コメント等いただければ、受講者も大変喜ぶかと存じます。次のページから、参加者につき１セットの評価用紙を用意してあります。

ご協力よろしくお願いいたします。

例

この研究発表の創造性を１～５までの数字で表してください。

受講者にコメントをお願いします。

Appendix B - Questions for participants for Reflections

(*)アスタリスクが付けられた質問は必須回答です。

() 今日あなたが創造的(自由)に考えた場面はどんなところでしたか？* (ポジション:1)

() 今日あなたが批判的に(しぼって)考えたところはどんな場面でしたか？* (ポジション:2)

() 自分自身の自由研究とのつながりを考えてみましょう。あなたの自由研究の準備で、どんなときに創造的あるいは批判的に考えるとよさそうですか?* (ポジション:3)

() 今日のグループ活動から、今後どんなことを進めていきたいと考えていますか？【8つの活動】から選んで考えてみよう。* (ポジション:4)

Appendix C- Whole Schedules for Shizuoka STEM Junior Project 2016

平成28年（2016年）

5　月			6　月			7　月			8　月			9　月		
日	曜日	行　事	日	曜日	行　事	日	曜日	行　事	日	曜日	行　事	日	曜日	行　事
1	日		1	水	水7	1	金	金12	1	月		1	木	
2	月	月4	2	木	木7	2	土		2	火		2	金	
3	火	憲法記念日	3	金	金8	3	日	藤枝科学教室	3	水		3	土	ステージ2⑥
4	水	みどりの日	4	土	る･く･る②	4	月	月13	4	木		4	日	藤枝科学教室
5	木	こどもの日	5	日		5	火	火12	5	金		5	月	
6	金	金4	6	月	月9	6	水	水12	6	土		6	火	
7	土		7	火	火8	7	木	木12	7	日		7	水	
8	日		8	水	水8	8	金	金13	8	月		8	木	
9	月	月5	9	木	木8	9	土	ステージ2⑤	9	火		9	金	
10	火	火4	10	金	金9	10	日		10	水	る･く･る⑥	10	土	ステージ3②
11	水	水4	11	土	ステージ2③	11	月	月14	11	木	山の日	11	日	ステージ3②
12	木	木4	12	日		12	火	火13	12	金		12	月	
13	金	金5	13	月	月10	13	水	水13	13	土		13	火	
14	土		14	火	火9	14	木	木13	14	日		14	水	
15	日	ステージ2開講式①	15	水	水9	15	金	金14	15	月		15	木	
16	月	月6	16	木	木9	16	土		16	火		16	金	
17	火	火5	17	金	金10	17	日	ステージ3①	17	水		17	土	ステージ2⑦
18	水	水5	18	土	ステージ2④	18	月	る･く･る④ 海の日	18	木		18	日	
19	木	木5	19	日		19	火	火14	19	金		19	月	敬老の日
20	金	金6	20	月	月11	20	水	水14	20	土	る･く･る⑦	20	火	
21	土	る･く･る開講式①	21	火	火10	21	木	木14	21	日		21	水	
22	日		22	水	水10	22	金	金15	22	月	Stage2 活動日	22	木	秋分の日
23	月	月7	23	木	木10	23	土		23	火	研究所訪問	23	金	
24	火	火6	24	金	金11	24	日	牧之原科学教室	24	水		24	土	る･く･る⑦
25	水	水6	25	土	る･く･る③	25	月	月15	25	木		25	日	
26	木	木6	26	日		26	火	火15	26	金		26	月	
27	金	金7	27	月	月12	27	水	水15	27	土		27	火	
28	土		28	火	火11	28	木	木15	28	日		28	水	
29	日	ステージ2②	29	水	水11	29	金	牧之原科学教室	29	月		29	木	
30	月	月8	30	木	木11	30	土	る･く･る⑤	30	火		30	金	
31	火	火7				31	日		31	水				

平成29年（2017年）

10　月			11　月			12　月			1　月			2　月		
日	曜日	行　事	日	曜日	行　事	日	曜日	行　事	日	曜日	行　事	日	曜日	行　事
1	土		1	火	火5	1	木	木8	1	日	元日	1	水	水15
2	日		2	水	水5	2	金	金8	2	月		2	木	木15
3	月	月1	3	木	文化の日	3	土		3	火		3	金	金15
4	火	火1	4	金	金5	4	日		4	水		4	土	
5	水	水1	5	土		5	月	月9	5	木		5	日	
6	木	木1	6	日		6	火	火10	6	金	金11	6	月	
7	金	金1	7	月	月5	7	水	水9	7	土		7	火	
8	土	STEMキャンプ	8	火	火6	8	木	木9	8	日		8	水	
9	日	STEMキャンプ	9	水	水6	9	金	金9	9	月	成人の日	9	木	
10	月	STEMキャンプ 体育の日	10	木	木5	10	土		10	火	月12	10	金	
11	火	火2	11	金		11	日	藤枝科学教室　郡	11	水	水12	11	土	建国記念の日
12	水	水2	12	土	ステージ2⑩	12	月	月10	12	木	木12	12	日	る･く･る発表会
13	木	木2	13	日	藤枝科学教室　郡	13	火	火11	13	金	金12	13	月	
14	金	金2	14	月	月6	14	水	水10	14	土		14	火	
15	土	ステージ2⑧	15	火	火7	15	木	木10	15	日		15	水	
16	日		16	水	水7	16	金	金10	16	月	月13	16	木	
17	月	月2	17	木	木6	17	土		17	火	火13	17	金	
18	火	火3	18	金		18	日		18	水	水13	18	土	
19	水	水3	19	土		19	月	月11	19	木	木13	19	日	
20	木	木3	20	日	る･く･る⑨	20	火	火12	20	金	金13	20	月	
21	金	金3	21	月	月7	21	水	水11	21	土	藤枝科学教室　郡	21	火	
22	土	る･く･る⑧	22	火	火8	22	木	木11	22	日		22	水	
23	日	藤枝科学教室	23	水	ステージ2⑪	23	金	る･く･る⑩	23	月	月14	23	木	
24	月	月3	24	木	木7	24	土		24	火	火14	24	金	
25	火	火4	25	金	金7	25	日		25	水	水14	25	土	
26	水	水4	26	土		26	月		26	木	木14	26	日	
27	木	木4	27	日		27	火		27	金	金14	27	月	
28	金	金4	28	月	月8	28	水		28	土		28	火	
29	土	ステージ2⑨	29	火	火9	29	木		29	日				
30	日		30	水	水8	30	金		30	月	月15			
31	月	月4				31	土		31	火	火15			

Appendix D- All Descriptions of Participants' Reflections

Result 4- Application of Creative Thinking on Participants' Group Inquiries

Categories	Sub-categories	Represented Descriptions
1		グループの課題を出し合ったとき。 課題を考えるとき 始めは大変だったけれど、たくさん考えているうちにどんどん浮かんできた 考えたのが二人に選ばれたから嬉しかった グループ研究の課題出し。 自由研究テストの答えを書くとき。 グループ研究の案を出すとき。 発表の時にまず、どんなことを言うか。 グループ研究の内容を考えたとき。 疑問、課題を自由に考えていたとき。 テストをしたときに熊野くんが～の内容の問を自由に考えた。 グループ研究の課題を出し合ったとき。 ｓｔａｇｅ３のテストの**最初**の問いの時。 疑問を出したとき 特に動物と会話したいと書いたとき テーマの案を出す場面 研究課題をたくさん出し合った時 たくさんの疑問を出したところ。 小学生、中学生の発表を高校生活に活かす方法。 テストの解答 目のつけるところ テーマ設定 グループ研究でやりたいテーマを思いつくままに書きだしたところ。 アンケートのとき。 これからの研究の課題をたくさんだしたとき。 新しく考えたグループ研究の課題決め 研究の案を考えるときによりおもしろく独創的な課題になるように創造的に考えました。 どのようなことが身近な不思議なのかをできる限り案としてだし、 課題について案を出したとき どのような課題にするのかについて。 課題設定 →何を解き明かすべきか様々な視点から変えて見ていったから 炭酸飲料をシェイクして人が空を飛べるほどの力を

		出すには、どのような疑問や課題を解決していけばいいかを考えたとき。 課題を考えるとき。 課題を出すとき 疑問と課題の案出し 課題、疑問を考えた時。 課題や疑問を出し合ったとき。 目的を決定するうえでいくつも案を出した。 課題は何かをはっきりさせるためにいくつも課題を出したところ 疑問や分からないこと、調べることをたくさん出す場面 チームのこれからの課題を挙げたとき。 自分のグループの課題を挙げていったとき。 今後の課題を細かく設定していった時。 活動の課題 活動の疑問 解くことになる疑問を出した時。 問題点を考えるとき
		もとの疑問が課題を解決する上で必要になってくるかを創造的に考えました。
3		実験方法を考えたとき。 考えられる実験方法を出す時 炭酸飲料の飛ばす力を確かめる方法について 布が水をはじくためには、どうすれば良いのかを考えたところ。 炭酸飲料が吹き出て来る勢いを測るにはどうすればいいか、案を出したとき。 どういうことを調べる必要があるのかを考えるとき 研究の方法 二酸化炭素から人工的に酸素を分離することについて、そのための方法を創造的に考えました。 グループ討論の中、ひたすらに圧力を測る方法を考えた。 例えば、風船をペットボトルの口につけてみたり、圧力計と言ってみたり。 実験対象の動物を決めるとき、身の回りにいる動物をできる限りだした。 みんなで実験方法を調べたとき。 実験の種類、方法 実験方法を考えたとき。 どの実験を行うかの順番を考える時。（パターン） 炭酸飲料の吹き出てくる勢いを測定するにはどうすればいいのかを考えたとき。 これからの研究の進め方や、実験の方法を考える時

		に創造的に考えました。どのような方向でシミのできない服を考えていくかを考えるとき 炭酸の入ったペットボトルを飛ばす方法、炭酸を充てんする方法を考えるとき どんな研究の進め方があるか 炭酸のデータを測る方法をたくさんアイデアを出したとき。 ミドリムシの培養方法を考えて実験の準備をしたとき。 実験方法 実験でどんなことをやってみるか、考える時。 具体的にどういう方法で実験を行うかを考えるとき 実験の計画を練るところ 人間から動物へ伝えることができるかもしれない方法 これからの実験計画をどうしていうか計画を立てたとき まず、 どんなことを証明していきたいのかを考えたとき インコで行う、人→インコの実験について考えたとき。 実験計画 ver1.5 をつくる際、細かい手順を書き出すとき。 また、キャップの開け方によって結果に違いが出てしまったり炭酸が漏れたりすることを防ぐにはどのような装置にしていけばいいか考えたとき。 インコの飼育方法の確立 ミドリムシの培養に使う 台所に有る色々な物 緑虫の培養液をなににするのか決めるとき 今後の実験をどのようにして行けばよいかを考えるとき 実験方法を確認するとき シャーレの洗い方 シャーレの拭き方 針なし注射器の使い方 実験方法を考えるとき 実験方法などで、うまくシミができるように考えた。 実験の手順を決める時。 実験方法をこれで良いか もう一度確認。 台所や家にある身近なものを思いつくだけ挙げたとき。(培養する液に何を入れるのかを 考えるために) 方法を考える時

		方法 実験方法を考えるとき 実験の仕方を考えるとき 詳しい、実験をしてみないとわからない方法、手順を考えるとき 砂糖などを炭酸水に入れる時に入れた衝撃で中身が吹き出てしまうのを防ぐ方法を探した時。 測り方を具体的にしたとき。 今回は、布にシミを作る実験をしました。この時に、実験を行う計画を考える、 実験方法を考えるとき
		基礎的な知識を調べるときや、 光合成について、広い範囲で調べたとき。 ビデオから何がわかったか、
		人の思想と、動物の思考の違い シミとは何かということを考えるとき 服のシミについてどのような種類があるか、 シミを作るものもっと多くする時にどれが良いのか考えたこと 実験の水のパターン。 さまざまなアルカリ溶液をだしたとき
		二酸化炭素を吸収する水溶液について、またより溶かす特徴が何かについて、創造的に考えました。 身近にあるシミのできるもと（原因）と、シミができる素材（布）を考え実際にシミを作る実験を行ったときに考えた。 炭酸の種類を考えたとき 二酸化炭素が空気に触れないような実験方法を考える時 水酸化リチウムの性質を調べた時 インコが怖がるもの、嬉しく思ったりするものが何か考えたとき。 インコが怖いと思うもの 嬉しい　ほしい
		必要物の案出し ミドリムシ、オオカナダモの実験に必要な材料を挙げたとき。 布の種類を決めるとき 水をはじくためのものを選ぶとき シミを作るものを決めるとき 必要物の案出し 実験の準備をする時に、何が必要かを考えたところ。 買うものを決める時 どんな器具があるのか調べた時。 そのときには何を使えばいいのかを考えたとき。

		実験に何が必要かや、 必要物 実験方法と実験に使う道具の案を出すとき 何が実験で必要になるのかを考えるとき 代用できるものを考えるとき 舞ちゃんがざっと出してくれたアルカリ性の物質の中でどれを使用するかなどを、その物質を使うことでいいことや悪いことなどを、創造的に出すことができました。 何が実験に必要なのかを考えるとき 素材選び 実験するアルカリ溶液を考える時に創造的に考えました。 二酸化炭素を溶液に溶かす装置 比べる炭酸飲料を決めた時。 道具 培養水に使う物が他に何かないか そこで、しみのもとと、しみを作る布を選ぶときに自由に考えました。
		財務計画の最終的に必要なものを考えたとき。 財政計画書を作るには？ →様々な要素を出していったから 財務計画を立てたとき 今の財務計画表に何が足りないのかを考えるとき
		どうしてこの研究をするのか？ →誰が必要としているのか、どうして必要にしているのかなど、たくさん考え方があるから。 グループ研究のニーズを決めるときに、どんなのがあるか、創造的に考えました。 ニーズを考えた時。 どんなニーズがあるか。 研究のニーズを考えた時 →様々な必要な物があるから 研究の目的について、どのようなニーズがあるのか、 活動のニーズを確認した場面。
		実験前にすることを考えるとき
4		カレーが布に乗っていたことについて、他の醤油、コーヒーなどの液体ではすぐに水に溶けたのに対して、水に浸けても広がらなかったことについて、どうするべきか考えた
		今回は主に実験や調査が主だったので創造的に考える部分は少なかったですが実験後の展開や考察について創造的に考えました。
8		グループごとで分かれて話し合いをしたとき.

		個人発表のとき。 それぞれの研究発表
		ほかのグループの発表の中で、自分たちに応用できる点はないか。 また他の人の意見も取り入れて自分の意見を膨らませた。 ほかのグループの案を理解するとき
x		今日は、批判的にしか考えなかった。
		自分の考えをまとめる時
		Arduino のプログラムが正しく動かなかったとき（修正の方法を探すとき）

Appendix D

All Descriptions on Result 5-
Application of Creative Thinking
on Participants' Independent Inquiries (Practices)

1		今後やってみたい課題、疑問を出し、 いままでの研究をもとに新たな疑問や課題を探すとき 調べたいことや課題を考えて行くとき そこからどんな疑問ができるかを考えるとき。 疑問と課題の決定 実験後に新たな疑問をたくさんだす 創造的に課題を出して 今後の課題を細かく設定していくとき 疑問 課題に対する案を考える際 課題に対する疑問を考えるとき。 失速角をどのように防ぐのか課題を出すとき 現時点での課題を探すときは創造的。
		私が明確にしたいものはなんなのか 知りたいこと どのようなことを調べたいのか、 どのようなことを調べたいのか どんなことを調べたいのかということ(疑問や課題)を出した時 まず、どんなことをしたいのかということをはっきりさせるために、 目的などを図にして整理する。（創造→批判）
		テーマ決め テーマを考えるとき
		目的を考える 目的を定める時は創造的に 目的を考える 目的を定める時 実験目的 目的を考えるとき どの様な目的で研究をするのか考えるとき
		なぜ研究をするのか なぜ研究をするのか 動機 自分の研究のニーズについて考える
2		予想するとき。
		仮説を立てるときには、今までの自分の知識や体験をもとにして、創造的に考える。 やはり仮説を立てるとき 研究では、課題に対する案や仮説を考える際に創造的 仮説であらゆる可能性を出す 仮説を考える際
		ゴキブリの羽についてどのようにして弾いているのかを創造的に考

		え、
		実験方法 実験を考える時 実験の計画で、どのような実験にするのか 実験などで。 実験内容を考える時 仮説を検証するための方法 実験方法 どの様な方法を取るのかを考える時 研究の計画 実験方法 実験の方法を考えるとき 実験方法を考えるとき 方法を考える 実験方法を考えたたり 実験を行う時、どう進めていくか考える時 実験方法・実験の計画を考える時や、 方法を考える 方法 実験方法を考えたたり、実験方法を決めるとき。 実験を行う時、どう進めていくか考える時に創造的に決めていきたい。 実験計画を立てるとき 実験方法のアイデアを出すとき 実験方法を考える時 方法を考えるとき テーマからどうしていけばよいか考える時 次の実験内容 実験方法をできるだけ細かく決める 実験方法を考えるとき 方法を考えるとき 実験方法を考えるときは創造的に考える。 身近にあるものを使って実験していくとき 仮説に基づいた、実験の方法を考えるとき。 どのような実験方法で明確にできるのか 実験方法など
		実験器具をつくり方や作る時
		財務計画を立てるときは、その目的を果たすにはどうすれすればいいのかを整理すると計画を立てやすい。 欲しいものを買う前に、細かくどの商品が良いか調べてから決めること 実験器具を購入するとき 行く場所や費用を考えたとき
		必要なものを考える そのために必要な物、ことを整理する。

			必要物の決定 必要なものを考えるとき 使う材料を決めるとき 必要なものを考える 実験を成功させる（正確なデータを集める）ために必要な準備 必要物 その実験を調べるために必要なものや準備するものを創造的に挙げていく。 実験の持ち物を探すとき 必要なものを買うとき 必要物を選ぶとき考える事 どのようなものが必要なのか 実験する時に必要なものを決める時
3			今後の計画 今後の実験について これからどんな実験ができる、どんな実験をすればよいのかを考えるとき 一つ目の実験の実験結果から、次の実験の方法を、目的を達成するために創造的に色々なパターンを考えて、実行していった。 今後の発展について、実験結果からいろいろな予想や利用方法が考えられる場合は創造的に考えたいです
			磁力の測定方法や、磁力を強くする方法 電磁石の強さを強くする方法を考えるところ。 石鹸を作るとき、どんな作り方で作るか決めるとき。 自分の自由研究では、結晶づくりで新たな方法を考えるとき 新しい実験の方法や結晶の作り方を考えるときは 朝顔をカバーするときカバー方法を考えるときに創造的に考えると良さそう
			もっと単純な実験にすることはできないか考えるときは創造的に。 電磁石の実験方法 クエン酸の必要性 酸とアルカリの使用法 今回の実験で、炭酸は砂糖や塩、金平糖などの物体が入っていると泡がたくさん出た。それと同じように、「これは違う」というものでも実験して、確かめることが大事だと思った。 酸を使って得る利点は何か 酸を使うことによる欠点は何か ズイナと比較する他の植物を決めるとき。 何の糖と比較して実験をするか 石鹸を決める時 実験に使う色素選び 朝顔の虫の取り方 ヨトウムシの取り方 カルマン渦をどのように生かせばいいのか、方法を考えるとき カルマン渦をどのような要素から減らしていくのか、方法を考えると

		き 寒天で培養する菌を決めるとき 葉の面積を測る方法として、方法のアイデアを３つ出して、そこから正確と言える条件に一番合っている方法のアイデアを使いました。 新しい進ませ方を考えるときに創造的に考えた。 強酸性の物質を探した時
		データの取り方 資料を選ぶとき
		正しく、正確にするために、実験を工夫しました。
		実験場所も重要になってくるので、どのようなことを知りたいのかということや害はないのかということを考える 実験場所を決める時など
4		考察のまとめ方 データや結果 考察をするとき。 考察は、創造的に出していった。
		基本的な実験の段階は終わったので、その理由を考えることや この実験の結果が出て考察をするときに、いろいろな原因を考える
		前に、行った実験が終わった時に創造的に考えるといいと思った。
		結果に対して導かれることは何か 出た結果は何を表しているのか また、結果から考えられることなども創造的に。 考察では結果からどのようなことが導けるのか考える
		自分のやっているものは、分類か、規則かを考える。
		翼で無駄になっている力を探す
5		表、グラフのまとめ方 数値のまとめかたには色々な方法がある
6		今までに行った実験をまとめるとき 出た結果をまとめるとき
		課題の解決策を考えるとき 課題の解決方法の案を考えるとき 問題への解決策を考える時など、これからの物事について色々な視点の考えでこれらの物事が変化するとき
		迎え角を大きくできる条件 装置がうまく動かないときなどは創造的に考える。 同じく、自由研究の時にも Arduino のプログラムが正しく動かない時があった。 ２年目の研究で、アナログの回路でやった時も同じく正しく動かない時があった。 デジタルもアナログも正しく動かない時に間違えを見つける力が必要だと思った。
7		
8		一時発表をして、どうしたらもっと良くなるか、アドバイスをもらうこと

		山崎財団に助成金の申請をするときに書く研究の方策を考えるとき。 どうしたら文章が読む人にわかりやすいかを考えるとき 原稿の書き方 レポートをまとめるとき 論文の構成を考えた時
		どんなことが最初に分かっていなければいけないか考える時 調べや、知識が必要になってくるということがわかった。
		パワーポイントの作り方 パワーポイントを効果的に作る方法 言いたいことを簡潔に、分かりやすく説明できるのではないかと思います。
9		様々な視点の見方

創造的思考

Creative Thinking

意見を否定、批判しない・恥ずかしがらずに何でも言う・できるだけたくさん意見を言う・意見を組み合わせる

批判的思考 

Critical Thinking

人に対する批判と意見に対する批判を区別する・お互いがそれを認めてから議論を始める・自分と反対の意見から始めてみる