Knowledge Modeling of the Inquiry-based Learning Instructional Process in Japanese High Schools

Ontology model of Instruction Based on the PPDAC Cycle

Hiroki Hayashi[1,*,†], Munehiko Sasajima[1,†]

[1]University of Hyogo, Nishimachi 8-2-1, Kobe, Hyogo, Japan, 651-2197

Abstract

The development of problem-solving skills has gained importance worldwide. Japanese high schools are aiming to develop problem-solving skills through inquiry-based learning to discover and solve problems. However, there is a lack of teachers capable of teaching inquiry-based learning, and instructional methods for inquiry-based learning have not been established. To increase the number of teachers who can teach inquiry-based learning, a systematic teaching method must be established. This study proposed the Problem-Plan-Data-Analysis-Conclusion cycle (PPDAC cycle) ontology as a knowledge model that facilitates the standardization of instructional methods in inquiry-based learning. First, knowledge regarding the states of understanding in inquiry-based learning were extracted and systematized. Next, Consequently, a knowledge model was constructed by structuring the systematized knowledge based on the PPDAC cycle. The constructed ontology validated through a survey of high school teachers and university professors. The results indicated that the proposed ontology could support inexperienced teachers in planning instruction for inquiry-based learning using the PPDAC cycle. The proposed ontology is a heavyweight one, and each concept definition has rich properties, is expected to help computers infer instructional strategies for inquiry-based learning in high schools and to build a system that outputs instructional plans according to students' abilities and learning environments.

Keywords

High school Education, Inquiry-based learning, PPDAC Cycle, Ontology, Knowledge Modeling

1. Introduction

The development of technology has ushered in the sophistication of abilities required of human beings. As the OECD international survey PISA 2012[1] measures problem-solving skills, the cultivation of problem-finding and problem-solving skills has gained importance 21st century. In response to these trends, inquiry-based learning along the problem-solving process has been popular in Japanese high school education in order to cultivate problem-solving skills[2].

The Japanese high school education curriculum contains a course referred to as "Period for Inquiry-Based Cross-Disciplinary Study" which is designed for students to conduct inquiry-based learning. In addition, other subjects have been shown to contain inquiry-based learning.

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*Corresponding author.

†These authors contributed equally.

happyman122055@gmail.com (H. Hayashi); sasajima@sis.u-hyogo.ac.jp (M. Sasajima)

This indicates that Japanese high school education actively promotes the development of problem-solving skills.

However, there are still certain problems yet to be solved. There are no government approved textbooks for the ”Period for Inquiry-Based Cross-Disciplinary Study” and there is no standard instructional content and methodology. Furthermore, there are no specific teachers specializing in teaching students, and teachers are assigned independently from among teachers of various subjects.

In addition, in Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has guidelines for school education in each subject. In the field of inquiry-based learning for each subject in the curriculum guidelines, the problem-solving process was exemplified.

In the field of inquiry-based cross-disciplinary study, the process of inquiry is presented as follows[3]: ”setting an issue, collecting information, organizing and analyzing, and summarizing and expressing.” In the field of Mathematics I, the statistical inquiry process is presented as follows[4]: ”problem - plan - data - analysis - conclusion” In the field of Informatics I, the following practical training process is presented as follows[5]: ”Discover a problem, Collect information and Define the problem, Searching for solutions and Developing a plan, Predicting Results and Execution of the plan, reflection, and then solve the next problem.”

People with experience related to the problem-solving process and who have written papers in university can understand that these three are practically the same process. However, it is doubtful that high school teachers can judge the three processes to be the same. Prior research[6][7] has indicated that the ability to teach inquiry-based learning is difficult without master level academic experience. Currently, 84.1 % of teachers may not have academic experiences to facilitate the discovery and solution of problems[8]. To teach inquiry-based learning, certain experience in this regard along with academic experience is necessary. Therefore, although inquiry-based learning are becoming increasingly important for developing problem-solving skills, teachers capable of teaching inquiry-based learning in high schools are limited.

Many high school teachers do not understand how to teach inquiry-based learning owing to their lack of academic experience. Therefore, they have encounter difficulties in planning instruction for inquiry-based learning. For example, the stage of ”discovering a problem” comprises six states: discovering a problem, formulating a question, setting a hypothesis, setting an objective variable from the hypothesis, searching for an explanatory variable that affects the objective variable, and determining an explanatory variable that leads to a solution. When the state of determining the explanatory variables that lead to a solution is reached, a researchable problem is considered to have been discovered. For inexperienced teachers to plan lessons, it is necessary to define the process of inquiry-based learning in further detail as presented in the Courses of Study. In addition, the process must be mapped to the content of the lessons that the students are to be taught, such that it can be put into practice.

This study aimed at the standardization of the teaching method for inquiry-based learning using the problem-solving process. First, we extracted and systematized the knowledge about the problem-solving process and then the procedural knowledge was structured.

For this purpose, an ontology engineering tool suitable for making implicit information explicit, systematizing knowledge, and standardizing knowledge in a certain domain was used. The proposed ontology is a heavyweight one, and each concept definition has rich properties. By using the ontology, we plan to support inexperienced teachers by inferring instructional strategies for inquiry-based learning in high schools and to build a system that outputs instructional plans according to the teachers' abilities, students' abilities and their learning environments.

The results of this study resulted in the creation of a guide for teaching inquiry-based learning and is expected to contribute to the development of teachers who can teach inquiry-based learning.

This paper is organized as follows. Chapter 2 describes related research on ontology engineering. In Chapter 3, we model the process of inquiry learning based on the PPDAC cycle, and in Chapter 4, we construct the ontology corresponding to the model. In Chapter 5, we discuss the evaluations of the constructed ontology received from high school and university teachers who are experts in inquiry based learning, and in Chapter 6, we summarize and discuss future prospects.

2. Related Works on Ontology Engineering

2.1. Ontology Design for Standardization

This study aimed to standardize instructional methods such that teachers with limited research experience can understand the instructional methods of teachers with inquiry-based learning instructional skills. In case of inquiry-based learning in Japanese high schools, there is a lack of teachers with appropriate academic experience, a textbooks, and teachers of different subjects teaching, etc. Therefore, there is a dearth of a support system to establish instructional methods. One solution to this situation is to build a model of instructional methods for inquiry-based learning. Therefore, we used ontology engineering, which is suitable for providing a common language, rendering the implicit information explicit, and systematizing knowledge.

Ontology engineering, as proposed by Mizoguchi[9], is a theory and technology for representing essential conceptual structures that exist in reality on computers. Concepts defined in an ontology can be used as a common concepts to represent knowledge and improve the sharing and usability of knowledge.

The concept class based on the is-a relation, which is the key to ontology construction, is not just a categorization class. It classifies concepts by clarifying the semantic differences between concepts[10]. We considered that the differences in the state of inquiry learning can be classified in inquiry-based learning instruction, which has been implicitly intellectualized.

2.2. Ontology and Education

Ontologies related to the field of education include: Ontology to support the design of complex cooperative learning places in education[11], organization of theoretical knowledge[12], ontologies for instructional design models[13], and support for searching instructional plans[14].

In the field of education, ontologies have been used to clarify tacit information and systematize knowledge.

2.3. Ontology and Knowledge Acquisition Methods

Regarding knowledge acquisition methods for constructing ontologies, there are methods for structuring general process knowledge[15] and expressing and describing inherent process knowledge, such as the proposal of knowledge expression for extracting inherent process knowledge from employees at nursing care facilities and the explicit description model of tacit acts called CHARM[16][17]. In addition, there is a study on the construction of a domain ontology in which procedural knowledge is constructed and tacit knowledge is acquired by a classical guitar expert[18].

Referring to these studies, we decided to extract knowledge from two types of experts. One is teachers in high schools who have enough experience in teaching inquiry-based learning. The other is teachers in universities who have enough experience in research. We construct a general process knowledge and evaluate the process knowledge based on the knowledge of experts.

3. Modeling of the Instructional Process

3.1. Problem-solving Process

There exist certain problem-solving models. Among them, we chose the PPDAC cycle, which is a statistical inquiry process that has been practiced in elementary, junior high[19], and high school[20] in Japan. The PPDAC cycle is also used in New Zealand[21], where advanced statistical education is provided. Therefore, we decided to construct procedural knowledge of the problem-solving process based on the PPDAC cycle, which is used in education in countries other than Japan and appears to be widespread in Japanese school education.

3.2. PPDAC cycle Overview

The five phases of the PPDAC cycle are Problem-Plan-Data-Analysis-Conclusion. In mathematics in the high school curriculum guidelines[4],the five phases of the PPDAC cycle consist of Problem - Plan - Data - Analysis - Conclusion. The Problem phase involves understanding the problem and setting it. The Plan phase assumes the data and plans the collection. The Data phase collects the data and organizes them into tables. The Analysis phase creates graphs and understands the characteristics and trends. Finally, the Conclusion phase involves drawing conclusions and reflecting on the results. This renders it difficult to understand what should be taught in each phase. Therefore, by extracting knowledge of the problem-solving process and structurally describing procedural knowledge using systematized knowledge, a method for teaching inquiry-based learning utilizing the PPDAC cycle becomes evident.

3.3. Knowledge Acquisition

Japanese high schools have a Super Science High School (SSH) , which aims to nurture the ability to think through scientific inquiry and to develop internationally competent human resources. Inquiry-based learning curriculum development and rubrics for evaluation have been developed in SSH. A rubric is a list of evaluation criteria comprisin several levels of scales and descriptive words. The rubric developed by SSH is an effective resource for acquiring knowledge regarding the problem-solving process of inquiry-based learning. Therefore, we used a rubric to extract knowledge about the state of inquiry-based learning.

In addition, standardized rubrics have been developed by eight SSH schools (standardized rubrics)[22]. The standardized rubric describes the perspectives (evaluation criteria) and depth of quality (evaluation standards) based on which the quality of students' efforts is judged in accordance with their problem-solving processes. The standardized rubric is also a useful resource for procedural knowledge, as it includes a section referred to as "Instructional Strategies" that describes student behaviors and stumbling blocks that are found in the relevant criteria. Therefore, we believe that it is effective for students to acquire knowledge of the problem-solving process based on the standard rubric developed by SSH, which incorporates the practice of advanced problem-solving practices.

3.4. Ontology Construction Steps

In this study, We adopted the following approach.

Step1 Knowledge related to the problem-solving process extracted.

Step2 Systematization of the extracted state of knowledge performed.

Step3 Structured procedural knowledge based on the PPDAC cycle.

In Step 1, terms related to the state of the problem-solving process were listed with reference to the descriptive terms in the standard rubric. A comprehensive list of terms created without considering the overlap between concepts, relationships between terms, or whether the term represented a class or a property.

In Step 2, we systematized the knowledge obtained in Step 1. The lower classes were created by specializing the upper classes using properties.

In Step 3, the knowledge systematized in Step 2 was structured based on the PPDAC cycle. The status of each phase was assigned, that is, we set up the state as initial, intermediate, evolving, and end states. We undertook structuring to consider the correspondence between the state of inquiry-based learning and the phases of the PPDAC cycle.

3.5. Ontology Evaluation Methods

Experts with extensive experience in teaching problem-solving inquiry-based learning evaluated the constructed ontology. In this study, we defined experts as those with at least four years of experience teaching inquiry-based learning in high school and/or research experience in university. We explained the PPDAC ontology to the Experts, who then responded to the questionnaire based on the constructed ontology.

The questionnaire consisted of 21 items to evaluate the ontology. Table1 presents the questions. The responses had a five choice (1: no good, 2: not so good, 3: neither, 4: good to fair, 5: good).

Table 1
Questionnaires for the experts

Q1	Readability of ontology
1-1	Did you understand the ontology overview of the PPDAC cycle
1-2	Do you understand classes and properties
1-3	Can you read the classification of the state of student understanding at the Problem phase
1-4	Can you read the classification of the state of student understanding at the Plan phase
1-5	Can you read the classification of the state of student understanding at the Data phase
1-6	Can you read the classification of the state of student understanding at the Analysis phase
1-7	Can you read the classification of the state of student understanding at the Conclusion phase
Q2	Appropriateness of ontology
2-1	Were the super-sub relation appropriate
2-2	Was the classification of process status appropriate
2-3	Was the definition of the Problem phase appropriate
2-4	Was the definition of the Plan phase appropriate
2-5	Was the definition of the Data phase appropriate
2-6	Was the definition of the Analysis phase appropriate
2-7	Was the definition of the Conclusion phase appropriate
Q3	Usefulness of ontology
3-1	Did the PPDAC cycle ontology enhance your understanding of procedural knowledge
3-2	Were the terms in the PPDAC cycle ontology helpful by structuring procedural knowledge
3-3	Was the process of procedural knowledge properly classified in the PPDAC cycle ontology
3-4	Was the PPDAC cycle ontology helpful in understanding the PPDAC cycle
3-5	Can you use this ontology to plan your instruction
3-6	Does this ontology enable you to conduct inquiry based learning
3-7	By using this ontology, can you formulate your evaluation criteria

4. Construction of PPDAC cycle Ontology

The PPDAC cycle ontology implemented on the ”Hozo” ontology editor[23].

4.1. Knowledge Extraction

The standardized rubric has four perspectives: setting the problem, planning and conducting the research, gathering and evaluating information, and reflecting on the results. For each perspective, the standardized rubric presents standards that represents steps to be achieved, signs of the learner corresponding to the steps, and instructional strategies. Using these as a reference, knowledge about the state of inquiry-based learning extracted and developed 93 concepts including 49 state concepts. We worked on the following. In terms of standards, we conceptualized the ”question state” based on the descriptive words ”being able to formulate a question” and the ”execution unknown state” and ”execution possible state” based on the descriptive words ”being a plan with a view”. In terms of signs, ”verbalization state”, ” un-considered state” and ”considered state” conceptualized based on the descriptor ”results and consideration cannot be separated and only results are obtained”.

4.2. Knowledge Systematization

Based on the extracted knowledge and the standardization rubric, we defined the class-is-a relationship in the states by setting properties for the upper and lower concepts. We defined and specialized the following superclasses: ”formulation state,” ”hypothesis setting state,” ”research readiness state,” ”data collection state,” ”analysis state,” and ”conclusion state.” The following is a concrete example of systematization of knowledge about the formulation state based on the standardized rubric. Figure1 shows the systematization of knowledge about the formulation state.

First, it can be read from the descriptive words of Standardized Rubric, standard 2 ”Can formulate a question” and standard 3 ”Can formulate a question or hypothesis based on the goal of the research,” that the state transitions from the question state to the hypothesis state.

Second, from the descriptive words in Signs 3 ”Although it contains ambiguous words, it is able to express what it wants to reveal through the research in the form of a goal or hypothesis,” we set ”what it wants to reveal” as the ”expected solution” to the question. A boolean of ”presence/absence of expected solution” was set for the property, and if it was False, it was structured as a ”question state” and if it was True, it structured as a ”hypothesis state”.

Third, the descriptive words in Signs 3 ”I have a hypothesis”, 4 ”I have a hypothesis based on numerous experiments,” and 5 ”If there are previous studies, I have a problem that can be compared with them” indicate that the state is ”hypothesis state” but is distinguished between a hypothesis with an objective basis and a hypothesis without such a basis, and that the state is not changed. The fact that the state does not change and that the hypothesis is not a hypothesis is a distinction. As a result, we found that the state does not change, but there is a granularity in the state. Therefore, we specialized the ”hypothesis state”, and set ”hypothesis setting/objectivity yes” and ”hypothesis setting/objectivity no”.

By systematizing knowledge in this way, we systematized knowledge as ”hypothesis setting state”, ”execution state”, ”data collection state”, ”analysis state” and ”conclusion state”. The ”hypothesis setting state” and the ”execution state” could only represent transitions of the states, whereas the remaining states could represent the transitions and granularity of the states.

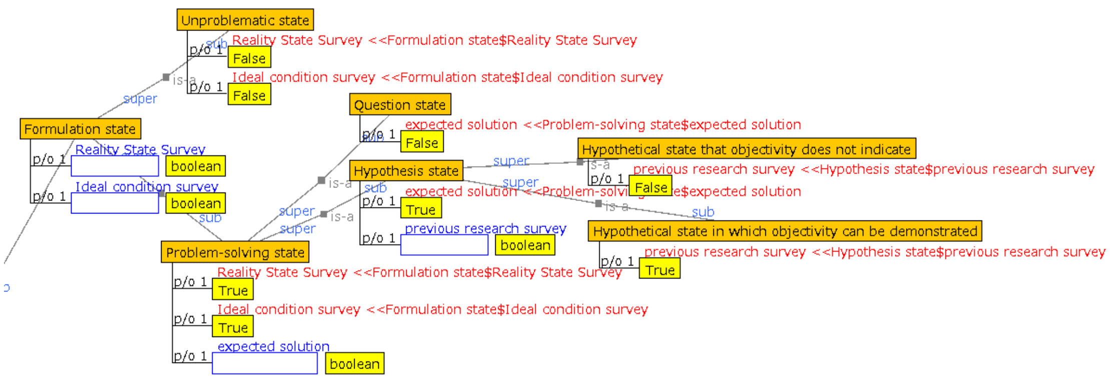

Figure 1: formulation state

4.3. Structuring Procedural Knowledge

Based on the PPDAC cycle, we structured the extracted knowledge.

First, ”process,” which was the upper class of each phase of the problem-solving process, was assigned initial, intermediate, advanced, and end states. As the initial state and the end state are states that must be reached, we set ”p/o 1”. Next, we set intermediate states for the relevant phases because intermediate states may exist to facilitate transition from the initial to the end state. Finally, the granularity of the states does not always result in a transition.

Therefore, for each phase, if there was a corresponding state, we set it as an advanced state. The ontology constructed in this study posted on the site[1]. Figure2 shows the structured procedural knowledge of the Problem and Plan phases. Figure3 shows the structured procedural knowledge of the Data, Analysis, and Conclusion phases.

Figure 2: Problem phase

[1] https://sites.google.com/view/education-ontology

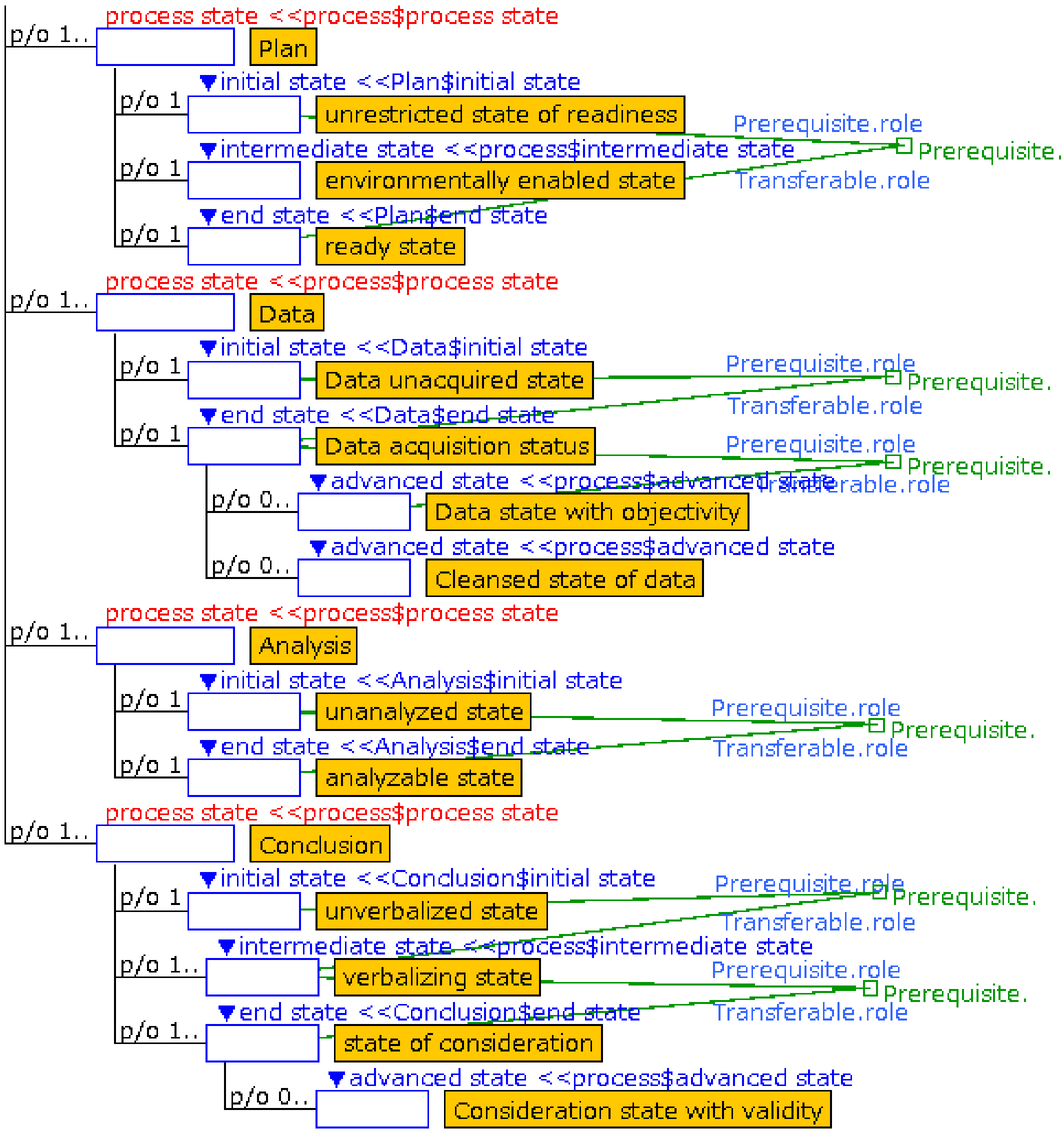

Figure 3: Plan/Data/Analysis/Conclusion phase

4.4. Ontology Questionnaire Results

Table2 presents the results of the questionnaire survey of high school teachers (n=5) and university teachers (n=4).

All items were generally answered positively, with a high percentage of ”good” and ”good to fair” responses. The results of the overall responses of high school and university teachers showed that the only items with ”good” and ”good to fair” responses were 1-1, 1-2, 1-5, 2-1, 2-5, 3-3, and 3-4. As evident, the readability of Overview, readability/appropriateness of Class/Property, readability of Problem, and readability/appropriateness of Data in this ontology were answered in the affirmative. The results also suggested that this ontology was effective for understanding procedural knowledge, useful for structuring procedural knowledge, and effective for improving the recognition of the PPDAC cycle. However, the readability and appropriateness of the Plan, Analysis, and Conclusion phases were not positive, suggesting the need for further study.

The responses of the high school teachers indicated, the items to which all five teachers answered "good" were 1-2, 1-7, 3-1, 3-2, and 3-4. The results of the high school teachers responses were as follows. In terms of readability, the results suggested that the program was effective in terms of understanding classes and properties an the classification of students' comprehension status in the Conclusion phase. They were effective in terms of usefulness, understanding procedural knowledge of the PPDAC cycle, raising awareness and recognition, and usefulness of the ontology terms. However, items 1-6, 2-3, 2-6, and 2-7 were answered as "neither." From the perspective of readability, the classification of students' comprehension states in the Analysis phase, and from the perspective of appropriateness, the definitions of the states included in the Problem, Analysis, and Conclusion phases need to be examined.

The university teachers' responses indicated, items for which only "good" and "good fair" were given for both readability and adequacy in the Problem phase, "Neither" and "good fair" for both readability and adequacy in the Analysis phase, and "Neither" and "good fair" for both readability and adequacy in the Conclusion phase. The items that included "neither" and "not so good" in both readability and appropriateness were the Plan, Analysis, and Conclusion phases.

5. Discussion

5.1. Ontology Evaluation

The results of the questionnaire for high school and university teachers were evaluated according to their combined overall responses. Regarding the readability and appropriateness of the proposed ontology, the readability and appropriateness of the Outline and Class Properties in this ontology, and that of the Problem and Data phases in each phase of the PPDAC cycle, received good evaluations. In the description of the questionnaire evaluation, there was a positive opinion regarding knowledge extraction that high school teachers could recognize that in the Problem phase, it is necessary to not only discover a problem, but also to facilitate a transition from problem discovery to hypothesis formulation and solution proposal.

There was a positive comment regarding the systematization of knowledge that the transition state of the inquiry activity was clearly expressed by the properties, and that what had been tacitly taught was made explicit. In terms of the effectiveness of the PPDAC cycle ontology, positive comments were observed on the understanding of procedural knowledge, usefulness of the ontology terminology, and awareness of the PPDAC cycle as a result of the structuring of procedural knowledge.

The high school teachers stated that the Data phase was not limited to simply acquiring data, but that the objectivity, organization, and systematization of the data phase and the developmental state of the PPDAC cycle made it effective in setting up instructional plans tailored to the students' level of understanding according to the school's actual situation. Further, it was clarified that the Problem phase was not merely setting a problem, and it was

Table 2
Results of Survey

	All					High school					University				
item	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1-1	0	0	0	1	8	0	0	0	1	4	0	0	0	0	4
1-2	0	0	0	1	8	0	0	0	0	5	0	0	0	1	3
1-3	0	0	0	1	8	0	0	0	1	4	0	0	0	0	4
1-4	0	0	1	2	6	0	0	0	1	4	0	0	1	1	2
1-5	0	0	0	3	6	0	0	0	2	3	0	0	0	1	3
1-6	0	0	2	1	6	0	0	1	0	4	0	0	1	1	2
1-7	0	0	1	1	7	0	0	0	0	5	0	0	1	1	2
readability	0	0	4	10	49	0	0	1	5	29	0	0	3	5	20
2-1	0	0	0	3	6	0	0	0	2	3	0	0	0	1	3
2-2	0	0	1	4	4	0	0	0	4	1	0	0	1	0	3
2-3	0	0	2	2	5	0	0	2	1	2	0	0	0	1	3
2-4	0	0	1	1	7	0	0	0	1	4	0	0	1	0	3
2-5	0	0	0	5	4	0	0	0	2	3	0	0	0	3	1
2-6	0	1	1	4	3	0	0	1	2	2	0	1	0	2	1
2-7	0	0	2	0	7	0	0	1	0	4	0	0	1	0	3
appropriateness	0	1	7	19	36	0	0	4	12	19	0	1	3	7	17
3-1	0	1	0	0	8	0	0	0	0	5	0	1	0	0	3
3-2	0	1	0	1	7	0	0	0	0	5	0	1	0	1	2
3-3	0	0	0	3	6	0	0	0	1	4	0	0	0	2	2
3-4	0	0	0	0	9	0	0	0	0	5	0	0	0	0	4
3-5	0	1	0	4	4	0	0	0	2	3	0	1	0	2	1
3-6	0	1	1	2	5	0	0	0	2	3	0	1	1	0	2
3-7	0	1	0	2	6	0	0	0	1	4	0	1	0	1	2
usefulness	0	5	1	12	45	0	0	0	6	29	0	5	1	6	16

reaffirmed that it included setting a solution. Therefore, it became clear that considerable time was required for instructional planning. The university teachers evaluated that the overall picture of the teaching of inquiry-based learning was well presented and effective at the high school level.

However, the Plan and the Analysis phases were evaluated to a certain degree in terms of readability and appropriateness, but not sufficiently. Thus, they need to be reviewed. In the Plan phase, it was reported that the properties of environmental factors in the state were abstract. It is considered possible to specialize the environmental factors into two: the environmental factor of whether data collection is possible and whether it is possible in terms of human resources. In contrast to other phases, the Analysis phase does not simply transition from one state to another. By clearly stating that the analysis state transitions according to the objectives, better systematization can be achieved.

Therefore, although better improvements were suggested in the systematization of knowledge, it can be judged that the proposed ontology has extracted the knowledge of inquiry-based learning, systematized the state of inquiry instruction in terms of the relationship between classes and properties, and structured the procedural knowledge of inquiry instruction based on the PPDAC cycle in a favorable manner. The procedural knowledge of inquiry instruction structured based on the PPDAC cycle.

5.2. Ontology validity

The validity was affirmed by comparing the results of questionnaires of high school and university teachers.

In terms of readability, the visibility of the tacit knowledge, on both the Problem and Data phases were positive, with the Analysis phase being generally positive, although there was one ”neither agree nor disagree” respondent each. However, the high school teachers were positive about the Plan and Conclusion phases, whereas the university teachers included ”neither” in their responses. University faculty members indicated that it was difficult for them to understand the terminology of the labels for the Plan and Conclusion phases. This is a problem of the notation of the labels, which can be improved immediately, and is not an essential problem for knowledge extraction and systematization.

In terms of appropriateness, both Data were positive, while the Analysis and Conclusion phases each contained one non-affirmative response. The Problem and Plan phase questions, answered by the high school and university teachers each contained a negative response. In the Analysis phase, both the high school and university teachers suggested points for improvement by setting the purpose to the properties of the analysis phase. In the Problem phase, it was suggested that it would be better to add a specific systematization of knowledge regarding the reality state survey, which is a property of the formulation state. In other words, the procedural knowledge of the reality state survey should be expressed using the knowledge extracted in this study. The Plan phase was an additional opinion regarding the particularization of environmental factors as well as readability. Therefore, the factors of the non-positive answers were not related to the extraction, systematization or structuring of the knowledge of this ontology: rather, they were related to the results of the answers that indicated better improvements.

In terms of usefulness, the results of the responses differed greatly between high school and university teachers. This is because procedural knowledge about the Problem and Analysis phases are not a one-way process in inquiry-based learning (research guidance) in university education, but is implemented through trial-and-error, and the expression of this knowledge is insufficient. However, it was found that the ontology was sufficiently useful in high school education if the inquiry-based learning of high school education were regarded as an introduction to the research activities of university education. In other words, the respondents were not positive about the effectiveness of the ontology as an ontology to be utilized up to university education; however, if it was limited to high school education, its effectiveness was evident.

Therefore, although there were concerns regarding readability, appropriateness, and the validity of the ontology, the survey of the factors that were answered by the respondents indicates that they were no factors that were considered inappropriate for this ontology, and that they were generally not affected by the ontology.

6. Conclusion

In this study, we constructed a PPDAC cycle ontology for the inexperienced teachers of inquiry-based learning using the problem-solving process. Based on a standardized rubric, we extracted and systematized the knowledge about the problem-solving process. Referring to the process model, we developed the PPDAC cycle ontology related to the problem-solving process. Further, we evaluated the ontology through consultations with experts in the field of education at both high schools and universities and found that the PPDAC cycle ontology exhibited certain evaluation and validity. Therefore, we clarified the following four points.

- We extracted and rendered the knowledge about the detail of the problem-solving process explicit.
- Systematized knowledge, that is, PPDAC ontology rendered tacit teaching methods explicit.
- The PPDAC ontology should support inexperienced teachers to plan their instruction for inquiry-based learning using the PPDAC cycle.
- The PPDAC ontology revealed that the Problem phase comprised many states and processes, which requires sufficient guidance and time, particularly for the inexperienced teachers.

The proposed ontology constructed in this study should help both the computer and the inexperienced teachers to understand the overall view in the teaching of inquiry based learning and helps the computer system to reason about the teaching methods and/or class planning for the teachers.

In the future, Two points to be discussed are as follows. The first is to verify that inexperienced teachers can use the system for planning inquiry-based instruction. The second is to construct a system that can automatically create an annual instructional plan for inquiry-based learning, as shown in Figure 4.

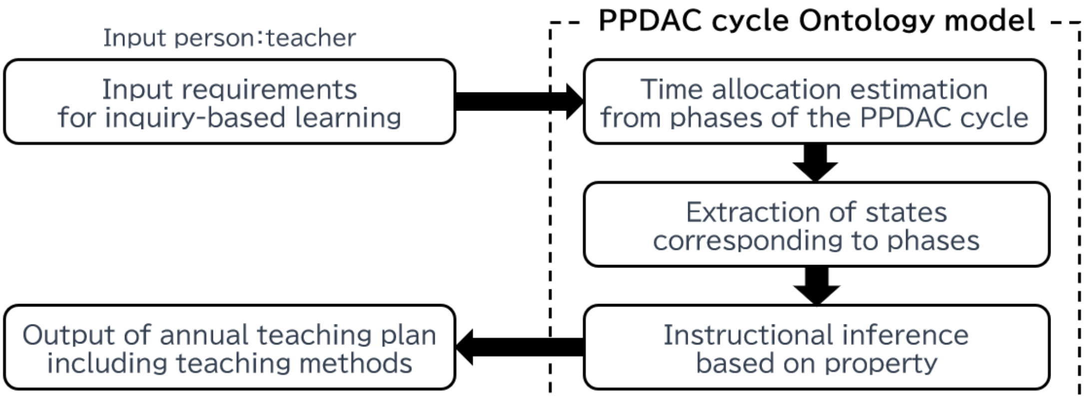

Figure 4: an automatic creation system in the annual instructional plan for inquiry-based learning.

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