A Knowledge Chunk Reuse Support Tool based on Heterogeneous Ontologies

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Abstract: To develop service robot applications, it is necessary to acquire domain expert knowledge and develop the applications based on the knowledge. However, since, currently, many of these applications have been developed by engineers using the middleware for robots, the domain expert knowledge is embedded in the codes and is difficult to reuse. Therefore, it is considered necessary to have a tool that supports the development of the applications based on machine-readable knowledge of domain experts. We also believe that the machine-readable knowledge can be reused not only for service robots but also for novices in the domain. To address the problems, this paper proposes a knowledge chunk (KC) reuse support tool based on heterogeneous ontologies. In this study, the parts of the reusable workflow, indexes required for a search, and a movie recording of robots movement based on the parts of the workflow are collectively known as a KC. Using the framework of case-based reasoning, the proposed tool accumulates parts of reusable workflows as case examples based on heterogeneous ontologies and facilitates search and reuse of KCs. It promotes domain expert knowledge acquisition and supports novices to learn the knowledge. As a case study, we have applied the proposed tool to teaching assistant (TA) robots. Two public elementary school teachers created workflows for TA robots using the proposed tool, and each teacher conducted a lesson with TA robots once. Through questionnaires given to the teacher, the proposed tool and TA robot application were evaluated to confirm their usefulness.

1 INTRODUCTION

In recent years, the development of service robot applications has attracted considerable attention in the service industry. To develop service robot applications, it is necessary to acquire domain expert knowledge and develop the applications based on the knowledge. However, since, currently, many of these applications have been developed by engineers using the middleware for robots such as Robot Operating System (ROS) [1], the domain expert knowledge is embedded in the codes and is difficult to reuse.

Therefore, it is considered necessary to have a platform that supports the development of service robot applications based on machine-readable knowledge of domain experts using ontologies, workflows, rules, etc. It is also considered that the machine-readable knowledge of domain experts can be reused not only for service robots but also for novices in the domain. In the model of skill acquisition proposed by (Dreyfus et al., 1986), learners acquire skills through five distinct stages: novice, advanced beginner, competence, proficient, and expert. From this point of view, we believe that the platform should be able to support the novice and advanced beginner's learning by reusing the knowledge of the proficient and expert.

Based on this, we have been engaged in the study and development of PRINTEPS (Yamaguchi, 2015), an AI and service robot application development platform. In the PRINTEPS, users can develop applications based on ontologies, workflows, and rules, and these machine-readable knowledge can be shared and reused. So far, we have applied this platform to teaching assistant (TA) robots at multiple elementary schools as case studies (Morita et al., 2018).

PRINTEPS provides a scenario editor to describe the workflows for robots' actions and human-robot interactions, and helps develop service robot applications that are executable on ROS. The scenario editor has several separate transverse lanes allocated to the corresponding agent of implementation, consisting of

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actors and tools, so that implementation procedures can be defined for each lane. With the scenario editor, workflows can be created while simultaneously overviewing the interaction between actors.

The scenario editor enables the developer to create workflows while reusing the entire workflows or individual operation processes; however, since end users such as domain experts usually do not know functions and properties of robots, it is difficult to identify and modify the reusable parts to suit the purposes of reuse when reusing the entire workflows. In contrast, it is also difficult to work out different combinations of operation processes when reusing the individual operation processes.

To address problems associated with workflow creation and reuse of processes using the PRINTEPS scenario editor, this paper proposes a knowledge chunk (KC) reuse support tool based on heterogeneous ontologies. Using the framework of case-based reasoning (Kolodner, 1997), the proposed tool accumulates parts of reusable workflows as case examples based on heterogeneous ontologies and facilitates search and reuse of KCs. It promotes domain expert knowledge acquisition and supports novices to learn and reuse the knowledge.

As a case study, we have applied the proposed tool to TA robots. Based on the workflows of TA robots given to several elementary schools, we created ontologies of teacher knowledge (teaching materials and methods), robot, and KCs and then established a KC base (KCB) based on these heterogeneous ontologies. Two public elementary school teachers created workflows for TA robots using the proposed tool, and each teacher conducted a lesson about a science learning unit "movement of pendulum" with TA robots once. Through questionnaires given to the teachers, the proposed tool and TA robot application were evaluated to confirm their usefulness.

2 KNOWLEDGE CHUNK REUSE SUPPORT TOOL

In this section, we explain the overview of the knowledge chunk (KC) reuse support tool based on hterogeneous ontologies. A chunk is defined on page 12 of reference (Tulving and Craik, 2000) as a familiar collection of more elementary units that have been interassociated and stored in memory repeatedly and that act as a coherent, integrated group when retrieved. In this study, the parts of the reusable workflow, indexes required for a search, and a movie recording of robots movement based on the parts of the workflow are collectively known as a KC. The database storing the KCs is called the KCB.

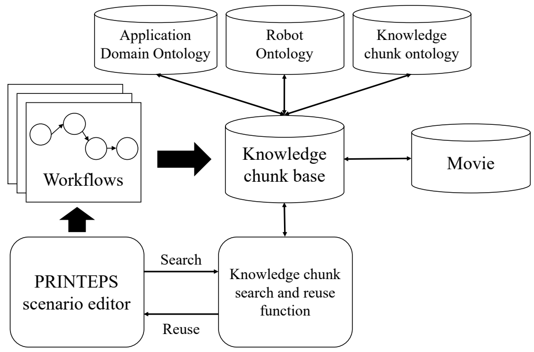

Figure 1: The system overview of the proposed tool.

Fig. 1. shows the system overview of the proposed tool. Using the framework of case-based reasoning, the proposed tool accumulates KCs as case examples based on application domain ontology, robot ontology, and KC ontology to facilitate the search and reuse of KCs from the viewpoints of promoting application domain knowledge acquisition and robot utilization. The proposed tool was implemented by expanding the PRINTEPS scenario editor.

The steps to reuse KCs using the proposed tool are as follows. Developers first create application domain ontologies by interviewing domain experts. Then, the part of the workflow corresponding to the KC is extracted, and the corresponding part of the movie is edited out. Based on the KC ontology, the developers create instances of KC classes and assign IDs to related operation processes, links to movies, and search indexes based on the application domain ontology. The user of the proposed tool can search the KCB using the search index created based on the application domain ontology and the robot ontology from the scenario editor. A list of KCs matching the search conditions will be displayed, and the selected KC that one wants to reuse is inserted in the scenario editor so that the user can edit the inserted workflow and reuse it afterward.

Currently, the proposed tool only supports end users to search and reuse of the knowledge chunk. The ontologies and knowledge chunk are manually created and stored by the developers.

3 ONTOLOGIES

3.1 Overview

The KCB is built based on the application domain, robot, and KC ontologies. These ontologies were built in the form of web ontology language

(OWL)[2] using the Ontology Editor *Protégé* [3]. We have defined 661 axioms, 26 classes, 10 properties, and 83 individuals in these ontologies.

3.2 Application Domain Ontologies

Application domain ontologies organize concepts and relationships for target application domains. As this study conducts lessons with teaching assistant (TA) robots as a case study, teaching material and method ontologies consisting of systematized teacher knowledge were created as application domain ontologies.

3.2.1 Teaching Material Ontology

The teaching material ontology organizes teaching material knowledge related to learning units of each subject based on the school curriculum guidelines set by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT). Fig. 2. shows the class hierarchy and part of the instances of teaching material ontology. We defined the "Learning unit" class as the root class and the "Learning unit" class of each subject (such as "Science learning unit" class) as the subclass of the root class. We also defined the field learning unit class as a subclass of each subject learning unit, such as the "Learning unit of dynamics field" class. Each defined class contains learning units that are taught such as "Regularity of a lever" and "Movement of pendulum."

This study selected an elementary school science lesson as a case study and therefore created teaching material ontology referring to "Content Classification of Science" of "Explanatory Manual of Elementary School Curriculum Guideline for Science Courses" provided by the MEXT.

3.2.2 Teaching Method Ontology

The teaching method ontology organizes the configuration for promoting teaching methods, such as its introduction and summary. Fig. 3. shows class hierarchy and part of the instances of the teaching method ontology. We defined the "Teaching method" class as the root class and the teaching method class for each subject as the subclass of the root class. In addition, we also defined the "Subject-independent teaching method" class that was common to all subjects, in which instances as "Starting and introducing the lesson" and "Summarizing and ending the lesson" were defined.

[2] https://www.w3.org/OWL/

[3] https://protege.stanford.edu/

Class hierarchy of the teaching material ontology

- Learning unit
  - Science learning unit
    - Learning unit of biology field
    - Learning unit of chemistry field
    - Learning unit of dynamics field
    - Learning unit of electricity and magnetism field
    - Learning unit of geoscience field
    - Learning unit of wave motion field
  - Social studies learning unit

Instances of the "Learning unit" class

- Birth of animals
- Formation and change of land
- Global warming
- Movement of pendulum
- Properties of light
- Regularity of a lever

Figure 2: Class hierarchy and part of the instances of teaching material ontology.

Class hierarchy of the teaching method ontology

- Teaching method
  - Subject-independent teaching method
  - Teaching method for science
  - Teaching method for social studies

Instances of the "Teaching method" class

- Creation of hypothesis and experiment design
- Experiment and verification
- Introduction of learning unit
- Main content of the lesson
- Preparation of examination questions
- Starting and introducing the lesson
- Summarizing and ending the lesson

Figure 3: Class hierarchy and part of the instances of teaching method ontology.

The study defines instances of the "Teaching method for science" class based on the guide issued by the MEXT, which is used by the teachers that took part in the case study.

3.3 Robot Ontology

The robot ontology organizes the functions of a robot and interactions between robots and people (in this case, teachers and pupils). From the results of the questionnaires given to the pupils and teachers on the lessons with TA robots in our previous case studies, it can be concluded that a lesson workflow in which there are interactions between teachers and robots or between robots and pupils, rather than a lesson workflow in which lessons are given only in one direction from the teacher or robot to the pupils, leads to a higher evaluation score by the teachers and pupils.

Fig. 4. shows the class hierarchy and part of the instances of the robot ontology. In the robot ontology, the "Use of robot" class was defined as the root class and the "Use of robot involving interaction" and "Use of robot having received favorable responses"

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Class hierarchy of the robot ontology

- Use of robot
  - Use of robot having actually received favorable responses
  - Use of robot involving interaction

Instances of the "Use of robot" class

- Approach from pupils to robots
- Approach from robots to pupils
- Approach from robots to teachers
- Approach from teachers to robots
- Creation of a feeling that the robot is voluntarily doing something for them
- Robot's supplementary explanation on teacher's remarks
- Speech awkwardly delivered by the robot
- Tell the pupils the start and end

Figure 4: Class hierarchy and part of the instances of robot ontology.

Table 1: Properties of the knowledge chunk ontology.

Property name	Domain	Range
learningUnit	Knowledge chunk	Learning unit
teachingMethod	Knowledge chunk	Teaching method
robotUsage	Process	Use of robot
hasProcess	Knowledge chunk	Process
processId	Process	String
chunkFile	Knowledge chunk	String
chunkMovie	Knowledge chunk	String

classes were defined as the subclasses. From the previous workflows, the interactions between robots and humans were extracted, and then only the workflows which pupils showed favorable responses were named and defined as instances for each class, including “Approach from robots to pupils.”

3.4 Knowledge Chunk Ontology

The KC ontology organizes the relationship between the processes constituting the KC and application domain ontologies. Fig. 5. shows KC classes and the instances used in the KC ontology. The “Knowledge chunk” class and “Process” class were defined as classes for the KC ontology. KCs are defined as instances of the “Knowledge chunk” class. The processes of the PRINTEPS scenario editor are defined as instances of the “Process” class.

Table 1 lists the properties of the KC ontology. The “learningUnit” and “teachingMethod” are properties connecting KC to target learning unit and teaching method. The “robotUsage” is a property connecting process to target use of robot. The “hasProcess” is a property connecting KC to the process related to use of robot. The “processId” is a property indicating the ID of the relevant process in the scenario editor.

Class hierarchy of the knowledge chunk ontology

- Knowledge chunk
- Process

Instances of the "Knowledge chunk" class

- Ask to identify conditions for determining the pendulum cycle
- Cut a carrot
- Explanation of acid rain using photos
- Explanation of super typhoon using body movements
- Greetings combined with precautions on robot lessons
- Guide to measurement experiment of pendulum cycle using Jaco2
- Have pupils debate on energy conversion
- Pepper gives a posted notice quiz
- Review of what was learned about the pendulum cycle
- Rhythmic pendulum
- Development to electric energy

Figure 5: Knowledge chunk classes and instances of the knowledge chunk ontology.

The “chankFile” is a property connecting KC to corresponding chunk file including process set that configures KC, its connection relation, and related module information used in those processes.

For teachers who do not know robots, since it is difficult to create a clear picture of robot movements by just referring to the workflow and reading the text, we prepared the “chunkMovie” property that connected the KCs with the corresponding movie files. We also aimed to encourage the reuse of KCs by allowing the teachers to learn from effective ways of the movies, which are difficult to pick up without experience. These ways are including dealing with pupils’ responses or pausing the interaction with the robot.

Because “learningUnit” and “teachingMethod” are properties that are dependent on each application domain, it is necessary to define object properties corresponding to their respective application domain ontologies when using the proposed tool for different application domains.

4 KNOWLEDGE CHUNK SEARCH AND REUSE

4.1 Knowledge Chunk Base

The KCB was created based on the application domain, robot, and KC ontologies. Fig. 6. shows an example of the KCB. In Fig. 6., the name, description, learning unit, teaching method, chunk file name, movie file name, and use and process of a robot are defined for the instance “Rhythm pendulum” of the “Knowledge chunk” class.

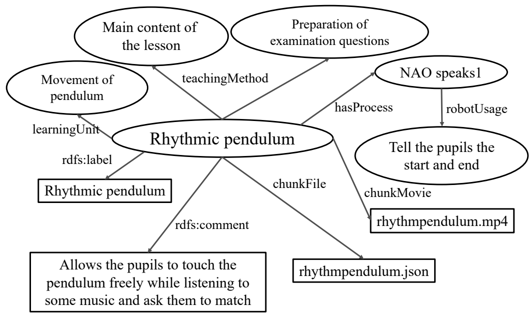

Figure 6: An example of KCB.

4.2 Knowledge Chunk Search

4.2.1 Search Query of Knowledge Chunks

Listing 1: Source codes of knowledge chunk search query.

```
SELECT DISTINCT ?s ?name ?description ?file ?
    movie
WHERE {
    ?s rdfs:label ?name ;
       rdfs:comment ?description ;
       ec:chunkFile ?file ;
       ec:chunkMovie ?movie ;
       ec:hasProcess ?process .
    {
      ?s ec:learningUnit ?unit .
      ?unit rdf:type ?selectedUnit .
    } UNION {
      ?s ec:learningUnit ?selectedUnit .
    }
    {
      ?s ec:teachingMethod ?method .
      ?method rdf:type ?selectedMethod .
    } UNION {
      ?s ec:teachingMethod ?selectedMethod .
    }
    {
      ?process ec:robotUsage ?usage .
      ?usage rdf:type ?selectedUsage .
    } UNION {
      ?process ec:robotUsage ?selectedUsage .
    }
}
```

The source codes of the KC search query written in SPARQL [4] are shown in Listing 1. The KC search query obtains a list of learning units selected by the user, the teaching method, the KC name (**?name**) associated with the instance in the use of the robot class, the description (**?description**), KC files (**?file**), and movie file passes. These are displayed in a specified format as the search result of the KC search screen shown in Section 4.2.2. In the positions described as **?selectedUnit**, **?selectedMethod**, and **?selectedUsage** of Listing 1, the instances of the learning unit, teaching method, and use of robot classes that have been selected by the user on the search screen are assigned.

[4]https://www.w3.org/TR/sparql11-overview/

4.2.2 Knowledge Chunk Search Screen

Fig. 7. shows the KC search screen, which can be called from the scenario editor. First, a category of the KCB is selected from the category pulldown menu. Then, the setting file for the selected KCB category is read, and the items set as the search condition are displayed on the search screen ("Leaning unit," "Teaching method," and "Use of robot," as shown in Fig. 7.). From the first pulldown menu of each search condition, any subclass just below the root class of the ontology corresponding to the search condition can be selected. For example, learning unit classes such as the "Science learning unit" class can be selected using the learning unit search condition. After the first pulldown menu is selected, the second pulldown menu can then be used to select a list of subclasses of the selected class. Upon reaching the leaf class, a list of instances of the selected class will be displayed in the last pulldown menu.

Once the search button is pressed, the search results will be displayed. The types of instances are inferred by the class hierarchies, and all instances of the knowlege chunk related to the selected class are obtained and displayed. After confirming the content of the KC by replaying the movie, the users can insert the workflow corresponding to the KC into the scenario editor being created. Fig. 8. shows a screenshot of the workflow of "Rhythmic pendulum". If a user selects the "Rhythmic pendulum" KC, the workflow shown in Fig. 8. is inserted into the scenario editor. Then, the user can reuse and edit the part of the workflow.

If intermediate classes other than the leaf class or its instances are selected, not only the instances of the selected class but also all instances belonging to its subclasses are included in the search target.

5 CASE STUDY

5.1 Overview

To evaluate the proposed tool, lessons with TA robots were conducted at an elementary school, in cooperation with two teachers in charge of Class 1 and 4 of the 5th grade. The two teachers had no experience in programming and development of robot applications, and this was their first time conducting lessons with TA robots.

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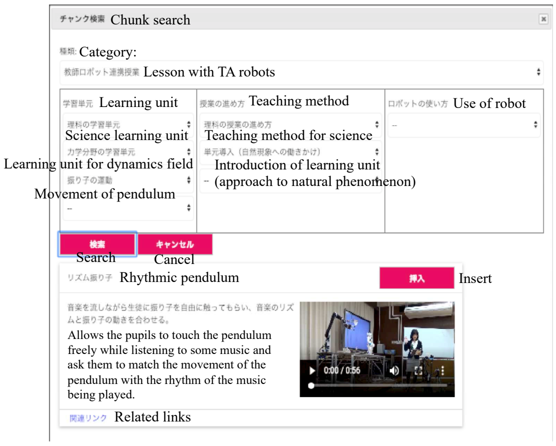

Figure 7: Knowledge chunk search screen.

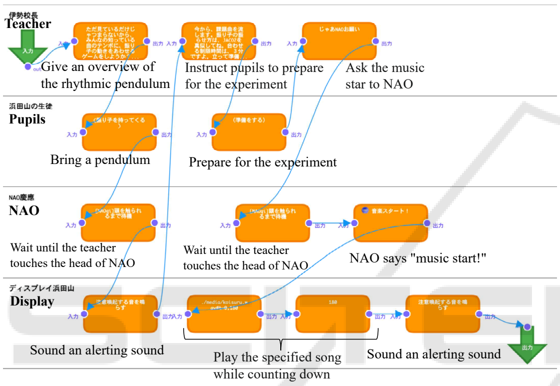

Figure 8: A screenshot of the workflow of "Rhythmic pendulum".

The content of the lessons given to both classes was the introduction of "Pendulum movement of the science unit." For both classes, "what determines the time necessary for a pendulum to make a single reciprocal motion" is set as the specific learning task to be attained at the end of the lesson.

TA robots applications were developed to conduct a lesson using the proposed tool; each teacher gave the lesson with TA robots once to each class. The proposed tool and the TA robots were evaluated by the questionnaires given to the teachers .

5.2 Creation of Knowledge Chunk Base

In this case study, the KCB was created based on the experience obtained from previously conducted lessons with TA robots. In this process, 11 KCs were extracted considering that there are different uses of the robot that are unique to each KC (the instances of the "Knowledge chunk" class as shown in Fig. 5). The movies corresponding to the KCs were also edited in such a way that the movie scenes depicting only knowledge transmission, practical operations, etc. were removed to make the running time in the range of 1 minute to 1 minute 30 seconds; comments were added as required. These measures aimed to shorten the time required by teachers to understand the content of the KC and allow them to follow the entire flow of the KC in a short time.

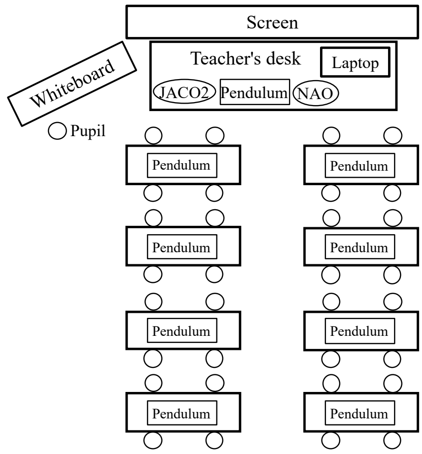

Figure 9: Lesson environment of case study.

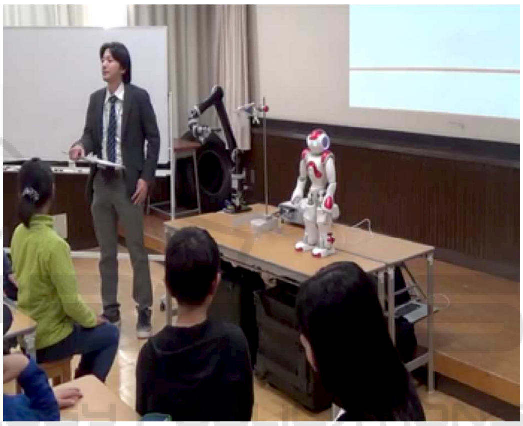

Figure 10: A Photograph from an actual lesson.

5.3 Lesson Environment

Fig. 9. and Fig. 10. show the lesson environment and a photograph from a lesson. Because it was necessary to set up the robots and desks on the day before the class and the teachers needed to rehearse the lesson, an audiovisual room was used considering classroom availability and other factors. NAO, which is a humanoid robot developed by Aldebaran Robotics, and JACO2, which is an arm type robot developed by Kinova, were arranged on the teacher's desk as TA robots. NAO works with teachers to enhance pupils' interest and understanding in the lesson. JACO2 puts

a weight on a pendulum and demonstrates swinging the weight. Eight tables were so arranged such that four pupils were at each table and each group could easily perform the swinging pendulum experiment.

5.4 Creation of Workflows for TA Robots

After the teachers learnt how to use the PRINTEPS scenario editor, they began to create workflows for TA robots on January 2019. They spent approximately two to three hours per session, requiring three sessions in total to complete the workflow.

At the time of the first workflow creation, they developed the entire lesson flow using the conventional scenario editor without using the KC search function. In the second session, a detailed workflow was created while referring to the use of the robot with the KC search function. In addition, during on the same day as the second session, an introductory lesson using NAO was given to the pupils to remove the barrier between pupils and the robots by introducing them to the robot functions, such as speech recognition and age estimation based on facial images. In the third session, which took place a day before the lesson with TA robots, final adjustments were made through a rehearsal.

5.5 Reuse of Knowledge Chunks

In the case study, three KCs (“Greetings combined with precautions on robot lessons”, “Rhythmic pendulum”, and “Pepper gives a posted notice quiz”) were reused by the teachers with the help of the proposed tool from the viewpoint of teaching material creation and use of a robot. Here, we would like to introduce the knowledge chunk of “Rhythmic pendulum”.

The rhythmic pendulum is a standard lesson taught at the elementary school that is intended to generate in the pupils mind a question concerning the change of cycle by allowing them to match the movement of the pendulum with the rhythm of the music being played within a certain time limit. In this KC, NAO gives a signal to start and stop the rhythmic movement of the pendulum and replay the music. Interactions were added to the workflow of Class 1, including those in which pupils ask NAO to turn on the music they want to listen to through NAOs speech recognition system; however, NAO rejects their request saying that it is in no mood to do that and then proceeds to tell them what it wants to listen to and succeeds in getting their approval. An interaction was also added to the workflow of Class 4, in which NAO directly talks to a pupil who is always slow to get prepared to listen to what the teacher says before the teacher starts explaining the rhythmic pendulum.

6 EVALUATION

We evaluated our system by asking the two teachers to complete a questionnaire on the reuse of teacher knowledge, use of robot, and user interface.

Regarding the reuse of teacher knowledge, comments such as “While it has the benefit of preventing to make the same mistake, there are also fears that too much dependence would hinder creativity and lead to a rigid teaching system” were made.

On the utilization of robots, teachers had the view that, “We were able to know in advance about typical cases that people who interact with a robot for the first time would experience and could use that knowledge to plan the classes” and “There is a clear need for further research on the timing to use KC search function.”

Their comments on the user interface included, “It is convenient to be able to find desired class scenes by narrowing down the categories and using a combination of categories.” and “It was easy to use because it was organized for each related item, but there seemed to be room to subdivide the items.”

It can be concluded from the above that it is necessary to clarify the process of workflow where each KC should be used and allow developers to dynamically change the degree of detail, priority, and organization of KC search items to suit the teacher’s knowledge level.

7 RELATED WORK

Many visual programming tools have been proposed to support the creation of robot applications (Pot et al., 2009; Alexandrova et al., 2015; Huang and Cakmak, 2017). Although many of these tools support a flow diagram representation and functional component search, it does not have the function to define the semantics of the combination of components based on application domain knowledge and use of robot knowledge, and make them reusable.

As a related work on the scenario design system for learning and teaching based on ontologies, SMARTIES has been proposed (Hayashi et al., 2009). In SMARTIES, the design intent of scenarios can be saved by creating a learning and teaching scenario based on the learning support theory, OMNIBUS (hereafter called OMNIBUS ontology). From the perspective of knowledge reuse, (Hayashi et al., 2009) mainly makes knowledge on methods reusable. Additionally, when the teacher uses SMARTIES to create a learning and teaching scenario, SMARTIES proposes the knowledge on methods applicable to an I_L event (concept for defining the relation between teaching and learning) based on OMNIBUS ontology. This is intended to support the design and reuse the learning and teaching scenarios based on learning and teaching theories.

The subject of this study is lessons with TA robots, and not ordinary lessons administered solely by teachers. Therefore, it aims to reduce the teachers' burden of creating workflows by creating knowledge and workflows that are mainly related to the use of robots, about which ordinary teachers, being non-experts on robotics, do not know much, reusable in the form of KC using the framework of case-based reasoning.

8 CONCLUSION

This paper proposed a knowledge chunk (KC) reuse support tool based on heterogeneous ontologies to solve issues associated with the creation and reuse of workflows using the scenario editor in PRINTEPS. Based on the workflows of lessons with TA robots given to several elementary schools, we created ontologies of teacher knowledge (teaching materials and methods), robots, and KCs. Then, we established the KCB based on these ontologies. Two public elementary school teachers created workflows for TA robots using the proposed tool, and each teacher conducted a lesson about a science learning unit "movement of pendulum" with TA robots once. The proposed tool and TA robot application were evaluated through the questionnaires given to the teachers to confirm their usefulness.

In a future study, it is necessary to clarify in which process of the workflow creation should each KC be used and help the users know the suitable time to perform a search. It is also necessary to make it possible to dynamically change the degree of detail, priority, and organization of KC search items to suit the teacher's knowledge level. In addition, the functions of PRINTEPS must be extended in a future work so that more flexible questions and answers, as well as conversations, can be exchanged by incorporating a more accurate speech recognition system and such mechanisms as general ontologies, rule-based system, and spoken dialogue system.

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REFERENCES

Alexandrova, S., Tatlock, Z., and Cakmak, M. (2015). Roboflow: A flow-based visual programming language for mobile manipulation tasks. In *2015 IEEE International Conference on Robotics and Automation (ICRA)*, pages 5537–5544.

Dreyfus, H. L., Dreyfus, S. E., and Athanasiou, T. (1986). *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. The Free Press, New York, NY, USA.

Hayashi, Y., Bourdeau, J., and Mizoguchi, R. (2009). Using ontological engineering to organize learning/instructional theories and build a theory-aware authoring system. *Int. J. Artif. Intell. Ed.*, 19(2):211–252.

Huang, J. and Cakmak, M. (2017). Code3: A system for end-to-end programming of mobile manipulator robots for novices and experts. In *2017 12th ACM/IEEE International Conference on Human-Robot Interaction (HRI*, pages 453–462.

Kolodner, J. (1997). Educational implications of analogy: A view from case-based reasoning. *The American psychologist*, 52:57–66.

Morita, T., Akashiba, S., Nishimoto, C., Takahashi, N., Kukihara, R., Kuwayama, M., and Yamaguchi, T. (2018). A practical teacher–robot collaboration lesson application based on printeps. *The Review of Socionetwork Strategies*, 12(1):97–126.

Pot, E., Monceaux, J., Gelin, R., and Maisonnier, B. (2009). Choregraphe: a graphical tool for humanoid robot programming. In *RO-MAN 2009 - The 18th IEEE International Symposium on Robot and Human Interactive Communication*, pages 46–51. IEEE.

Tulving, E. and Craik, F. (2000). *The Oxford Handbook of Memory*. Oxford University Press.

Yamaguchi, T. (2015). A platform printeps to develop practical intelligent applications. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, UbiComp/ISWC'15 Adjunct, pages 919–920. ACM.