An Environment for Interactive Creation of Experiential Knowledge

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Abstract

To properly realize human-computer collaboration, it is necessary to consider it as a process of knowledge creation and to express and utilize the information generated by the associated activities. In this research, an approach called knowledge experience design is proposed as a solution. In an environment based on knowledge experience, the target activity is centered on knowledge creation where humans and computers collaborate through understanding, modifying, and applying them to changing situations. The new method of knowledge experience focuses on individual activities (user experience) and shares the knowledge gained from personal activities as knowledge to improve the quality of other activities. The effectiveness of this method was confirmed by considering the curator's activities in the museum as a Knowledge Experience and evaluating a prototype system. Furthermore, it was confirmed that Knowledge Experience Design could apply to user experience and co-design of system components. This research shows that Knowledge Experience Design is effective as a new design method for human-computer collaboration. In the future, Knowledge Experience supports applying human-computer collaboration to many scenes, working with technologies such as AI and IoT.

Chapter 1

Background of Knowledge Experience research

As computers increasingly control and automate important activities and decisions in our lives, there is a growing need to reaffirm the role of humans and design appropriate human-computer collaboration [1]. Computer automation is an invaluable asset in increasing work efficiency and in expanding human capabilities. For example, an e-commerce website allows consumers to instantly find and purchase from a huge variety of products. In addition, the items are shipped automatically and will arrive the next day. As the variety of activities automated by computer programs begin to cover those that are integrated with human activities, the need for humans and computers to collaborate on an equal footing where humans and computers utilize each other's outcomes equally to carry out their activities arises. It has been identified that such collaborative work requires mutual understanding of objectives and tasks and sharing and management of progress [2].

Despite such needs, a prominent problem in human-computer collaboration is that it is difficult for humans to obtain enough information to understand and use the output of computers [3,4]. On the other hand, there is also a lack of support for input so that humans can fully utilize the results of their thoughts [5,6]. To solve these problems, it is necessary to consider the collaboration between humans and computers as a knowledge creation process and to express and use the information generated by the activities.

Much of the attention to human-computer collaboration is being devoted on how a human can make use of or accept the computed results. Such relations are most notable in activities where the roles of humans and computers are predefined clearly. To support such relation, it is necessary to support humans in interpreting and understanding the computed output so that they may perform subsequent actions. In activities in which the content of the work, or its processes, are more fluid and require to deal with constant changes or unexpected events, still a greater role is allocated to the human that possesses sufficient knowledge and experience who is expected to respond to the situation. In other words, such roles cannot be automated. Even if they were, it would be largely unreliable since knowledge is lacking to respond to the unexpected or unknown future event. Reliance on knowledgeable humans to appropriately respond to changes and unexpected events becomes a serious limitation when resource is scarce. One way of overcoming such limitation is to support knowledge creation when it is necessary. In particular, when faced with a new unexpected situation, it would be necessary to first acquire existing knowledge that could be basis for dealing with the new situation, prepare to modify the knowledge by exploring and understanding it, and then to implement the changes and execute it. In an ever-changing situation, it is necessary to repeatedly adapt existing knowledge to the changing situation and constantly create new knowledge. Such task can be performed by any agent, human or computer, and their collaboration can be considered as a knowledge co-creation environment. To use existing knowledge or to appropriately adapt them, it is first necessary to understand the knowledge so as not to misuse it or not to make unintended changes. The created new knowledge should also be immediately available to others. This applies to any agent that intends to make changes and to create new knowledge, human or computer. Considering the different roles that humans and computers play, the relationship between humans and computers should evolve from a knowledge-consuming collaboration to collaborative knowledge creation, i.e. co-creation. A corresponding co-creation environment can support humans in accessing knowledge and in creating knowledge with sufficient quality. Knowledge management (KM) is an approach for sharing and utilizing the knowledge acquired by individuals as an organization (creating organizational knowledge). It is also closely related to the learning theory of knowledge acquisition by individuals and knowledge engineering (KE), which is an approach for handling knowledge on a computer. In order to realize the creation, sharing, and utilization of knowledge between humans and computers as an information system on computers, it is possible to incorporate the idea of organizational knowledge creation (knowledge management approach) and combine it with KE and learning theories.

In this work, an example of designing an environment based on the concept of Knowledge Experience is presented. Knowledge Experience is an activity to systematically utilize information, gain new findings and learning, and obtain high-quality activities. In an environment based on the concept of Knowledge Experience, knowledge is cyclically and sustainably generated, reused, and executed as a real activity. In the creation and use of knowledge, it is always a challenge that there is not a small amount of knowledge that cannot be used even if it is shared, and it is known as Inert Knowledge [7]. In response to this, an approach that promotes the use and application of knowledge by sharing "when," "how," and "why" is being practiced in the field of education [8]. However, to date, no example has applied that approach to the handling of knowledge on a computer. By applying this idea and recording and sharing the situation of the knowledge gained from the experience, it is expected to keep the knowledge activated and realize an environment based on the concept of Knowledge Experience.

To make the Knowledge Experience a sustainable knowledge-creating activity, it includes the following: (1) Supporting individual findings and learning (individual learning); (2) Express and records the activity content so that others can understand and reuse it; and (3) share it as new and useful information (organizational learning). The findings and learning in this work correspond to creative activities in individuals and small groups (Mini-C, Little-C [9]), not creativity at the organizational or social level (Pro-C, Big-C [9]) such as business innovation and invention. These are creative activities that have a narrow range of influence but can be initiated frequently and can be expected to maintain and improve continuous activities.

This work first presents the design requirements for an environment in which humans and computers can carry out creative activities on an equal footing from the perspective of knowledge-centric human-computer collaboration. The next chapter presents the design, implementation, and analysis trials for a knowledge-creating environment. Then, Knowledge Experience Design (KED), a software design method that realizes the utilization of empirical knowledge and knowledge creation, is proposed. The following chapters show that software based on KED facilitates knowledge creation. In addition, it demonstrates the application of KED to the co-design of system user experience and component device design. These show that KED contributes to realizing an environment where humans and computers can grow and cooperate.

Chapter 2

Design requirements of Knowledge Driven Human-Computer co-Creation Environment

This chapter reviews human-computer collaboration efforts and presents a new process that enables humans and computers to communicate and understand each other from a systematic perspective on knowledge. In addition, environmental design requirements for appropriately combining and executing human activities and computer automation in response to diverse and changing situations are proposed. Specifically, the focus will be on Knowledge Engineering (KE), Knowledge Management (KM), and learning theories. As to lay down the basis of the approach, a comprehensive and systematic literature survey is preformed and analyzed, and the design requirements are organized to address the issues and solutions for realizing the environment.

In the following, firstly, the position of knowledge in the collaboration between humans and computers is clarified, and the validity of focusing on knowledge in this work is discussed. Next, the representation of knowledge in the field of computer science is summarized, and the rationale of performing a literature review on KE, KM, and learning theories is explained. Furthermore, the result of the literature review is discussed, and an environment in which humans and computers can create, share, and utilize knowledge on an equal footing is considered. Finally, in conclusion, (1) the process of creating high-quality organizational knowledge, and (2) the design requirements of the software system that supports the creation of organizational knowledge are presented.

2.1. Significance of Knowledge in Human-Computer Collaboration

Knowledge plays an important role in the collaboration between humans and computers. In this chapter, the significance of knowledge in human-computer collaboration (HCC) is summarized. It argues that a survey of knowledge-related efforts (KM, KE, learning theories) is an effective approach for designing a creative HCC environment.

2.1.1. HCC concepts and challenges

To begin with, Bainbridge [10] describes HCC as in human decision-making, the computer gives instructions or advice to the operator, reduces human error, visualizes the situation/state, and assists the operator when the task load is high. In addition, Terveen [4] states, Human-computer interaction involves (1) agreement on goals to be achieved, (2) planning, assignment and coordination of responsibilities, (3) tracking of progress toward goals, and (4) adaptation and learning. The typical approaches of HCC can be categorized into two as in Table 2.1.

Table 2.1 The two approaches for HCC [4]

①	Human Emulation	
	Overview	An approach to making computers work with humans by giving them human-like capabilities and allowing them to behave like humans. This is

		accomplished by developing a model of human-human collaboration, focusing on collaboration in language, and then applying that model to human-computer collaboration.
	Technical focus	Design a format for representing beliefs, goals, plans, and actions, and develop a model for collaboration that uses them. Also, develop algorithms for communication planning and plan recognition.
②	Human Complementary	
	Overview	An approach that attempts to make computers work with humans in order to complement them by exploiting their unique capabilities. It involves designing a division of responsibilities that assigns appropriate and clear roles to each agent, and using interaction techniques to facilitate effective human-computer communication.
	Technical focus	Design interaction models that divide the responsibility between humans and computers, and develop natural ways for humans and computers to communicate.

Cummings [5] states that the challenge for HCC is how can know the proper balance between humans and computers in a complex system involving humans and computers. The main engineering interest in HCC at the time was to automate as much as possible and minimize the amount of human interaction. In contrast, the model shown in Table 2.2, which is an extension of the SRK model [11], is presented as a classification of behaviors in response to external information and is analyzed as follows: skill-based behavior is a good candidate for automation if the performance and accuracy of sensors and other devices are sufficient. It is further concluded that rule and knowledge-based reasoning is suitable for HCC.

Table 2.2 Classification of human behavior [5]

Skill-based behavior	A highly automated sensory-motor behavior, usually acquired after a certain period of training.
Rule-based behavior	Behavior based on procedures, rules, and routines.
Knowledge-based behavior	Behavior that involves the selection of appropriate skills and rules/judgments based on the situation.
Professional knowledge-based behavior	Behavior that involves the exercise of knowledge under very unusual conditions, based on extensive experience.

In recent literature, the goal of HCC remains unchanged: "to realize (1) mutual understanding of purpose and task, (2) sharing of progress, and (3) independent joint management between humans and computers" [9]. Typical approaches also remain unchanged and are classified into two categories: (1) incorporating a cognitive model into a machine learning system (cognitive computing-based approach), and (2) human-computer collaboration (human-in-the-loop-based approach) [12]. Furthermore, as Shneiderman [1] points out, the challenge for HCC is similarly "how to balance human control and computer automation".

How to balance human control and computer automation" has also been discussed in the area of safety technology. In the area of safety technology, efforts are being made to achieve collaboration between humans and agents (computational resources, such as embedded systems or other computer-based systems, and interconnected physical devices) for cyber-physical systems (CPS), focusing on trustworthiness. The CPS is designed to be an interacting network of physical and computational components. Tehrani at el. [13] states, "it is important to integrate humans into CPS as a human-in-the-loop cyber-physical system (HiLCPS) rather than placing human context outside system boundaries". They also point out that "HiLCPS is a heterogeneous system with high uncertainty and complexity related to humans, so it is necessary to clarify the role that humans should play." Jirgl at el. [14] states that "obtaining information about human interactions with devices or processes and predicting the likelihood of human reaction within a variety of conditions and influencing factors is the challenge of HiLCPS". The approach from the safety technology domain also shows that the same issues as for HCC remain unresolved. Thus, it can be seen that the positioning of HCC and the approach to its realization have not changed significantly, and the issues are typical of those organized by Cummings [5].

2.1.2. Positioning knowledge in HCC

The Issues of HCC are expected to be resolved by focusing on knowledge. In this section, the significance of focusing on knowledge as an approach to solving the challenges of HCC is summarized. An appropriate division of roles between humans and computers is possible in activities where it has already been established that:

1) the necessary process is identified;
2) activities that make up the process are identified;
3) and, the skills, rules, algorithms, and parameters necessary for each activity are identified.

For such activities, it would be possible to allocate appropriate roles and recognize resources (trained personnel, sensor devices to collect the desired data, algorithms for control and decision making, and interfaces between humans and computers). In other words, HCC is almost ready for the skill- and rule-based activities described by Cummings [5]. However, for rule-based activities, there are still some issues to be realized, such as "explainability of automation (by AI)" being discussed for understanding the situation and selecting rules according to the situation [2,3].

When considering how to respond to changes and unexpected situations, it is necessary to create and apply appropriate rules and knowledge while anticipating new situations. In other words, it is necessary for humans and computers to collaborate on the level of co-creation. Advances in machine learning and other AI-related technologies have improved the accuracy of recognizing situations, and have enabled computers to learn new rules and knowledge necessary for making decisions. However, as mentioned earlier [2,3], humans cannot understand the rationale behind the decisions made by computers, and since humans cannot understand the rationale, they cannot provide feedback to the learning and inference algorithms, and these issues have been recognized and discussed as challenges for AI.

In contrast, rules and standards are treated, shared, and used as knowledge in business activities, especially in companies. KM is the concept of sharing knowledge within an organization, using it in activities, and incorporating the knowledge gained from the activities as new knowledge. In KM, there is a continuous effort to not only apply existing rules, but also to carry out organizational activities while dealing with newly defined rules. Therefore, in this work, it is considered that the realization of rules and knowledge-based activities shown by Cumming [5] will lead to the realization of HCC, and the focus will be on knowledge-related efforts in the computer field.

2.2. Review of knowledge initiatives in the computing field

As discussed in the previous sections, the perspective of association with KM is considered to be important for the realization of HCC. Regarding knowledge, there have been various efforts in the computing field. In this section, the knowledge-related work in computing will be summarized through a systematic review to clarify how KM relates to the computing field. Specifically, Scopus is used to list and count the keywords attached to each article in the "COMPUTER" area with the keyword "Knowledge" every five years from 2001 to 2020. Based on the results, the aim is to organize the context in which knowledge is handled on computers. The actual search conditions are as shown in Table 2.3.

Table 2.3 Search criteria for knowledge related articles in computer field

Search expression	(TITLE-ABS-KEY("Knowledge") AND (LIMIT-TO (SUBJAREA,"COMP")) AND (LIMIT-TO (PUBYEAR, *year1*) OR LIMIT-TO (PUBYEAR, *year2*) OR LIMIT-TO (PUBYEAR, *year3*) OR LIMIT-TO (PUBYEAR, *year4*) OR LIMIT-TO (PUBYEAR, *year5*)))
Search date	2020/12/2 13:00 JST

As a result of the search, Figure 2.1 shows the top 20 keywords used between 2001 and 2020 and the number of references per 5 years. For the top 20 keywords with the highest frequency of occurrence during the period 2001-2020, the five-yearly changes in the number of references can be summarized as follows. (Actually, 19 keywords, excluding the keyword "Article," which is related to the type of literature, are organized.)

1) Knowledge-Based Systems has the highest number of publications in the past 20 years, including

Decision Making, and is on the rise.

2) There has been a remarkable increase in automated knowledge generation, as in Learning Systems and Data Mining.
3) As for the technologies for using knowledge on computers, Semantics technology (Semantics, Ontology,) is active, but other basic technologies (Information Systems, Optimization, Algorithms, Knowledge Representation, Knowledge Acquisition) are slowing down.
4) Initiatives from the perspective of human learning (Students, E-learning, Education) are on the rise.
5) Human Computer Interaction is on the decline.
6) Systematic efforts focused on knowledge and its use (Knowledge Engineering, Knowledge Management, Information Management) are noticeably declining and slowing down.
7) Artificial intelligence, which refers to all human intellectual activities, is on the rise but slowing down.

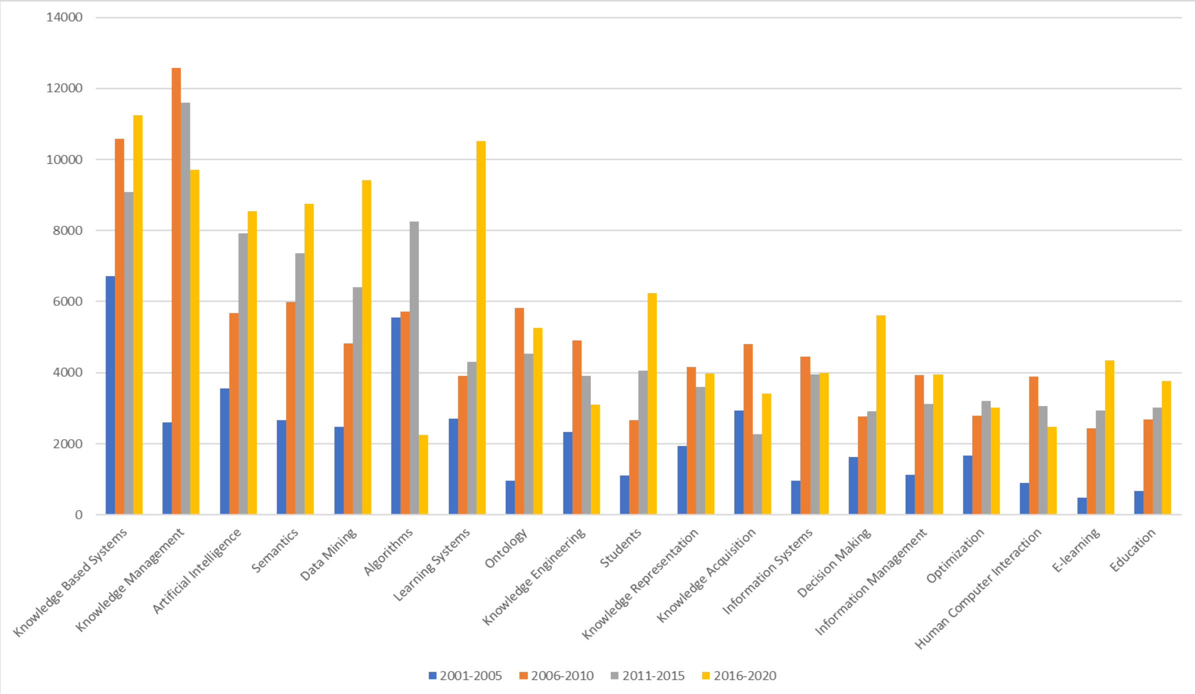


Figure 2.1 Transition of keywords used in knowledge-related literature in the CS field

In this way, efforts focusing on knowledge on computers are centered on "automated creation of knowledge" and "application of knowledge" rather than on a systematic approach to knowledge. This indicates that in the recent past, automated knowledge creation technologies, such as machine learning, have been applied and achieved results, and that knowledge-related efforts have moved from the theoretical phase to the application phase. This also indicates that, from a medium- to long-term perspective, it is time to take a new approach to knowledge from a systematic perspective in preparation for the next change. Focusing on KM, KE, and learning as a systematic perspective on knowledge is expected to deepen our understanding of knowledge handling, further evolve the current focus on automated knowledge creation and knowledge application and develop the relationship between humans and computers from mere cooperation and collaboration to co-creation (where humans and computers work together from corresponding positions). The following sections describe a survey based on literature on the knowledge lifecycle (the process of knowledge creation, sharing, and use) and the methods and technologies that realize each process. Furthermore, a discussion of issues and solution ideas in the realization of knowledge-centered human-computer collaboration is presented.

2.3. Literature survey method

In this survey, the results of previous literature surveys are utilized in order to efficiently conduct a comprehensive and systematic survey. Specifically, the literature survey papers on knowledge that have been conducted so far are the main targets of the survey, and in addition, the literature that each of the literature survey papers has surveyed will be surveyed as a supplement. The literature to be surveyed was searched using Scopus and selected as literature survey papers related to both KE and KM, as well as KE or KM and literature survey papers related to Learning. First, candidate papers were searched in Scopus, and then the literature survey selection and exclusion criteria were applied to the search results. Each criteria is shown in Table 2.4. (Since the literature search and selection was conducted on January 27, 2020, papers whose publication year was up to 2019 are included.)

Table 2.4 Search and selection criteria for the literature studied

Scopus search criteria	A	TITLE-ABS-KEY ("Knowledge Engineering" AND "Knowledge Management" AND "Literature Review") AND (EXCLUDE (PUBYEAR, 2020))
	B	TITLE-ABS-KEY (("Learning") AND ("Knowledge Engineering" OR "Knowledge Management") AND ("Literature Review")) AND (EXCLUDE (PUBYEAR, 2020))
Target literature selection criteria	a	Top 10 papers judged to be useful as literature survey papers (usefulness is judged by the number of citations)
	b	10 most recent reports reported by the end of 2019 (based on publication date as of January 27, 2020)
Subject literature exclusion criteria	①	(After summary and full-text review) The content of the paper can be clearly judged as not related to KE or KM.
	②	The English version of the paper is not available.
	③	Matched by other search conditions and selection conditions (articles that were already matched)

Search criteria A matched 302 literature survey papers, and search criteria B matched 40 literature survey papers. From the results of each search, 40 papers (hereinafter referred to as "main 40 papers") were the main subjects of the survey. (The retrieved articles and the results of the selection decision are shown in Appendix A.)

2.4. Survey Results

2.4.1. Overview

As a result of the full-text review of the 40 main papers, the main themes of each paper can be classified as shown in Table 2.5. In the 1980s and 1990s, KM was viewed as a management resource in organizations (groups, companies) and has been used for organizational growth up to the present. As shown in Table 2.5, literature reviews on the application of KM for corporate growth (Table 2.5 category A) was conducted mainly from 2000 to 2010, and there have been continuous studies on KM since then. Since the beginning of the 2010s, the purpose of using knowledge has begun to change from the growth of individual companies to the sustainable maintenance of supply chains and even to the maintenance of society (Table 2.5 categories B-E), indicating that the scope of management (the purpose of using knowledge) has become broader.

Table 2.5 Categories of major themes of the main 40 papers

Category		Articles
A	Significance, concepts, and techniques of KM in enterprises	Benbya et al. [15], Hung et al.[16], Kim et al.[17], Anantatmula and Knungo [18] , Clark [19], Rickenberg et al.[20], Konno & Iijima [21], Hakim and Sensuse [22], Shikhli and Hammad [23], Balaid et al. [24], Scarborough and Swan [25], Schneckenberg [26]. Brachos et al. [27], Ordóñez et al. [28], Meher and Mishra[29], Ahmad and Karim [30]
B	Significance, concepts, and techniques of KM in small groups	Twongyirwe and Lubega [31]: Small Medium Enterprises, Revere, et al. [32]: Public Health, Bryson et al. [33]: Public Policy, Ibragimova and Korjonen [34]: Health Governance

C	Significance, concepts, and techniques of KM in projects	Van Waveren et al. [35]: Project Based Organization, Mafereka and Weinberg [36]: Community of Practice, Rashid et al. [37] : Open Source Software Project
D	Significance, concepts, and techniques of KM in supply chains	Evangelista and Durst [38]: Logistics service provider, Cao et al. [39]: Supply chain collaboration, Roy [40]: Sustainable Supply Chain, Jha and Karen [41]: Supply Chain Management
E	Significance, concepts, and techniques of KM for sustainability	Evangelista and Durst [38]: Environmental sustainability, Fazey et al. [42]: Environmental management, Duru et al. [43]: Biodiversity-based Agriculture, Roy [40]: Sustainable Supply Chain, Sanguankaew and Ractham [44]: Sustainability
F	Other applications	Dreyer et al. [45] : Smart Services
G	Issues in KM and KE integration	Liao [46]: The need for KE as a tool to realize KM, Gavriova and Andreeva [47]: Necessity of cooperation between KE and KM, mutual complementation, Freitas et al. [48]: The need to apply knowledge management methods to KE
H	Technologies to effectively apply KM	Hannah and Simeone [49]: Ethnography, Elicitation, Pesquita et al. [50]: Semantic Web, Ontology, Linked Data, Bourguin and Lewandowski [51]: Ontology, Tagging, Venkitachalam and Busch [52]: Elicitation of Tacit knowledge, Clewley et al. [53]: Elicitation, Sensuse and Bagustari [54]: Collaboration Learning

In addition, for each of the literature selection criteria, the literature was categorized into three levels according to the degree of embodiment: theory (concept) level, proposal/introduction of feasible methods/tools level, and application/evaluation of methods/tools based on case studies level (Figure 2.2).

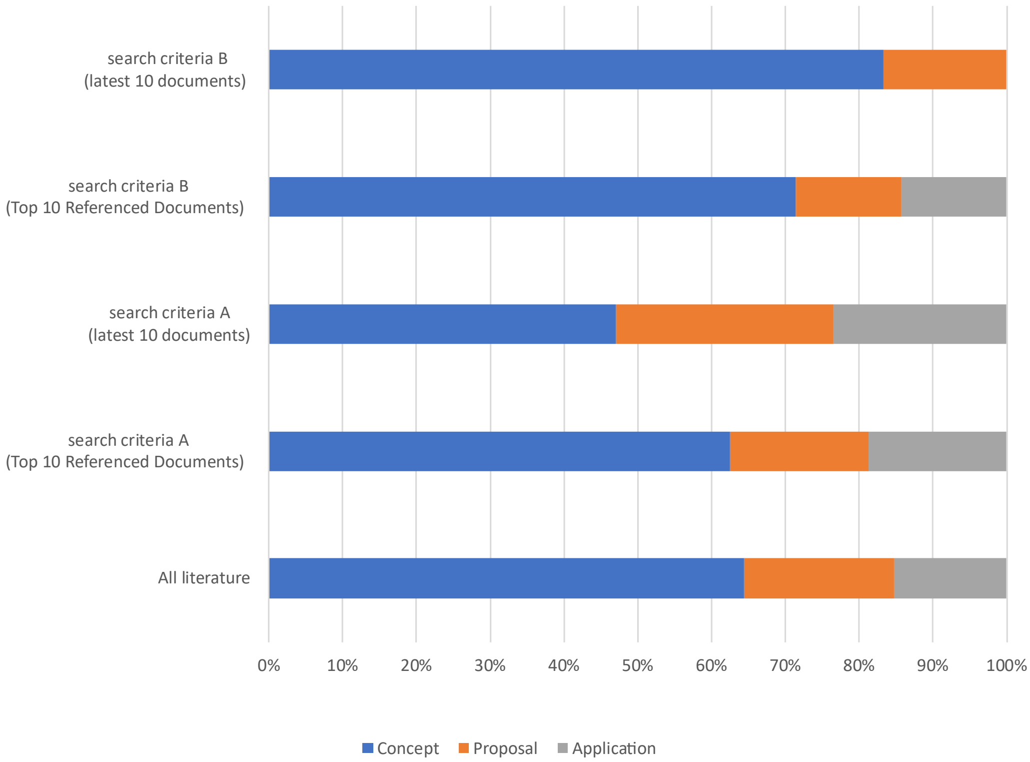


Figure 2.2 Degree of embodiment of the proposed knowledge theories, methods, and tools

Furthermore, the literatures in each selection criteria can be categorized by the dependency of the proposed theory, method, or tool on the application domain, as shown in Figure 2.3. (See Appendix B for details of each survey.)

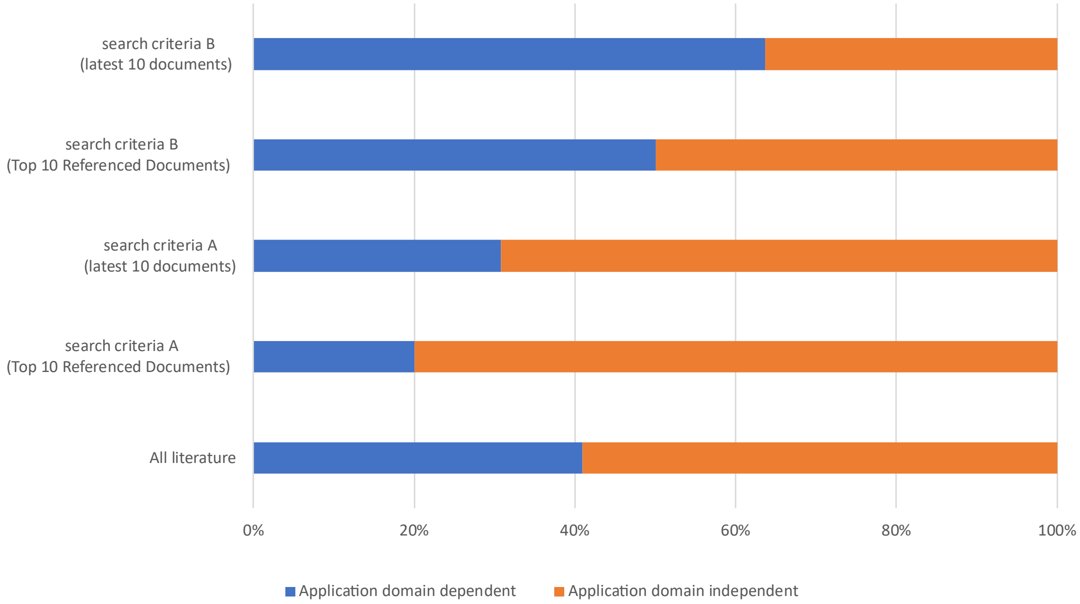


Figure 2.3 Application domain dependency of the proposed knowledge theories, methods, and tools

In terms of the degree of embodiment of the efforts, most are at the concept level. In the results of search criteria A, there are few efforts related to the application to specific fields. However, in the results of search criteria B, half are works in specific application domains, and in particular, more than 60% in the latest survey report are works on applying knowledge to specific domains.

2.4.2. Relationship between KM and KE

Understanding the relationship between KM and KE, which are systematic perspectives on knowledge in the computing field, and the efforts that have been made to address them can help us understand the issues related to knowledge in the computing field today. Benbya et al. [15] introduces KM as follows.

> A systematic and systematic process for acquiring, organizing, and communicating employee knowledge so that other employees can use it more effectively and productively at work [55].

In addition, Evangelista and Durst [38] consider KM as a method, and compare definitions from several literatures as follows to show its characteristics as a method.

> There are various perspectives on how to define KM. One practical definition is to view KM as a systematic way to create, share, and leverage knowledge inside and outside the organization [56].
>
> The main role of KM is to sustainably handle current and future knowledge resources by considering social, economic and environmental aspects [57].

Thus, it can be seen that KM is a method that realizes the process of creating, sharing, and utilizing organizational knowledge based on the knowledge possessed by individuals in an organization/company.

On the other hand, Gavriova and Andreeva [47] explain KE as follows.

> KE as a subfield of intelligent system development research provides tools and methods to enhance the process of extracting knowledge from individual employees and the use of the results in the organization.

The explanation of Studer et al. [58] is as follows.

> The goal of KE is to change the process of building KBS (Knowledge-Based Systems) from art to engineering.

Regarding the collaboration of KE and KM as academic disciplines, Gavriova and Andreeva [47] point out the differences in terminology, for example, the difference in terms indicating the externalization of individual knowledge (Elicitation and Acquisition). This points to the fact that KE and KM have been pursued as parallel efforts. Thus, there has been little bridging activity (research) such as discussion and collaborative efforts between KE and KM, which should have the greatest relevance as academic fields dealing with knowledge, and no significant results have been seen.

Liao [46] states that it is necessary to apply the methods that have been worked on in KE as tools to realize KM. Freitas et al. [48] discuss the significance of applying KM methods as a management method for classifying and standardizing the knowledge handled in KE. In this way, the need for KE and KM to complement each other and solve knowledge-related problems, which have been loosely linked, has been noted in several literature surveys.

The classification H in Table 2.5 shows that in the literature survey over 2017-2018, perspectives have been proposed to apply techniques from the KE field to KM. Hannah and Simeone [49] present the idea of using Ethnography for knowledge externalization. Bourguin and Lewandowski [51] propose the application of ontology and tagging as a way to represent the structure and relationships of knowledge. In this way, techniques and methods that have been worked on in the KE field are proposed to be applied to KM, and it is expected that future results will be achieved through collaboration between the KE and KM fields.

Regarding the treatment of knowledge in connection with other specialized and applied fields, the scope of integration is expanding. Since 2015, diverse efforts have been reported and the application of KM methods has been shown to be effective for domains, such as smart services using IoT and AI, as reported by Dreyer et al. [45]. In particular, AI has attracted much attention, with XAI (eXplanable AI) being treated as a theme at various conferences on its explanatory nature [2]. Human-AI Collaboration and Human-Centered AI [1] are also beginning to be studied from the perspective of human-AI co-creation.

As described above, efforts to collaborate with fields such as supply chain management (SCM), distribution, medicine, agriculture, and Smart Service (AI) have been focused on KM, which is the use of knowledge in business activities, and there has been no collaboration with KE. In the future, there is a need to deepen the collaboration between KE, KM, and knowledge-applied fields, such as externalization/sharing method of tacit knowledge in business activities and methods to improve explanability and comprehensibility in smart services.

2.4.3. Knowledge life cycle (Create-Share-Utilize process)

To consider an environment in which humans and computers can create, share, and utilize knowledge on an equal footing, it is necessary to understand the life cycle of knowledge.

As shown by Benbya et al. [15], the knowledge utilization process and lifecycle model are not unified in each initiative, and it is not possible to find a standard model of the knowledge utilization process and lifecycle (the process of creation, sharing, and utilization) from the main 40 papers. However, based on many literatures, the knowledge life cycle can be organized as (1) knowledge creation, (2) knowledge organization, (3) knowledge formalization, and (4) knowledge sharing and utilization. (Table 2.6)

Table 2.6 Knowledge Lifecycle [15]

	Phase	Activity
1	Creation	Externalize individual knowledge to generate organizational knowledge
2	Organization	Classify and associate knowledge to manage as an organization
3	Formalization	Expressing knowledge formally
4	Sharing and utilization	Sharing knowledge (allowing access to knowledge)

Figure 2.4 shows the results of classifying the 40 main papers based on the phase of the life cycle in which the papers are focused. Most of the 40 main papers are interested in the phase of knowledge organization. Few efforts have been made to focus on the formalization phase, which is the phase of externalizing and generating the knowledge gained by individuals. Like the knowledge life cycle shown in Table 2.6 the generation phase in which an individual transforms learning into knowledge is missing. This means that the corresponding phases are considered out of range for KE and KM.

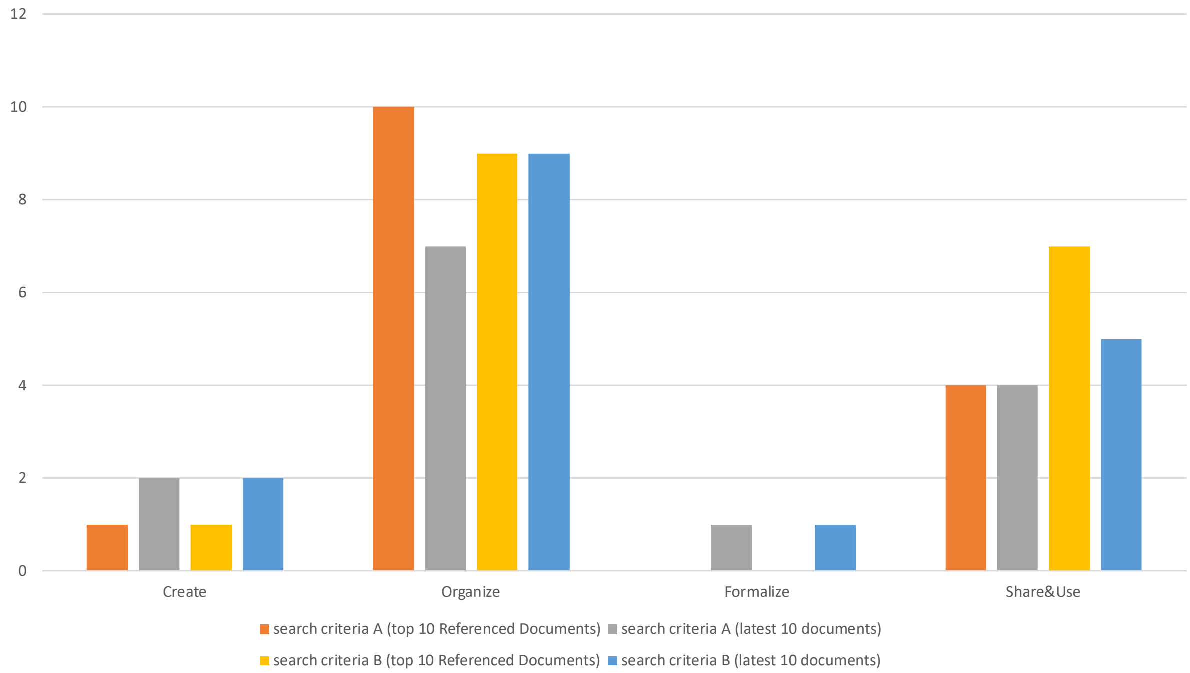


Figure 2.4 Phases of the life cycle that the main 40 papers focus on

The literature surveyed by the 40 main papers (2621 references, including overlaps between references) was classified in the same way based on their abstracts (Figure 2.5). The trend of the literature surveyed by the main 40 papers is similar to that of the main 40 papers, with a further amplification of the classification of the main 40 papers (focusing on the Organize phase, with many concept-level efforts). The papers surveyed by the main 40 papers include papers that discuss Creation and Formalization, which are not sufficiently treated in the main 40 papers, and are considered to be useful as a reference for research in this area.

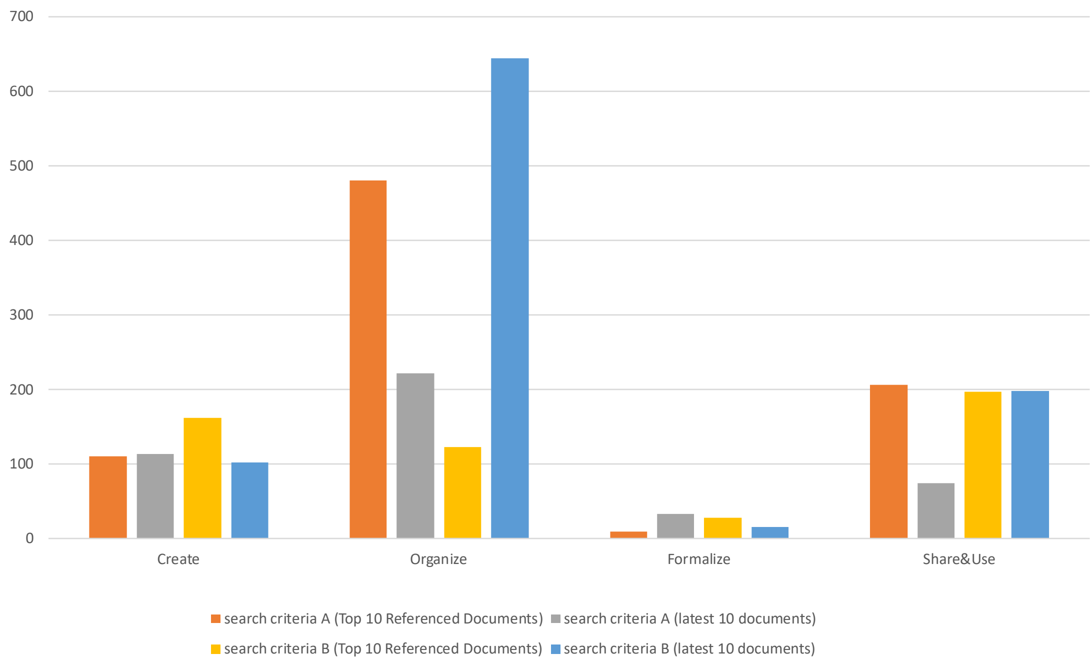


Figure 2.5 Phases of the life cycle that the papers referenced by the main 40 papers focus on

2.4.4. Papers referenced from multiple surveys in the main 40 papers

The focus of attention in the treatment of knowledge in the computer field can help us to consider the issues related to knowledge. In this section, the literature surveyed by the 40 main papers is discussed in terms of the literature surveyed in multiple references. The fact that the literature was commonly selected as the target of the survey by multiple literature surveys indicates that the literature is of high interest. The top 10 documents are shown in Table 2.7.

Table 2.7 Papers referenced from multiple surveys in the main 40 papers

Frequency	Title	Paper	Referenced By
9	Working knowledge: How organizations manage what they know	Davenport and Prusak [59]	Benbya et al. [15], Kim et al. [17], Clark [19], Schneckenberg [26], Brachos et al. [27], Twongyirwe and Lubega [31], Mafereka and Winberg [36], Rashid et al. [37], Fazey et al. [42]
7	The Knowledge-Creating Company	Nonaka and Takeuchi [60]	Kim et al. [17], Balaid et al. [24], Van Waveren et al. [35], Rashid et al. [37], Sanguankaew and Ractham [45], Pesquita et al. [50], Venkitachalam and Busch [52],
6	Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues	Alavi & Leidner [61]	Benbya et al. [15], Hung et al. [16], Kim et al. [17], Anantatmula and Kanungo [18], Sanguankaew and Ractham [44], Venkitachalam and Busch [52]
6	A dynamic theory of organizational knowledge creation	Nonaka [62]	Kim et al. [17], Van Waveren et al. [35], Mafereka and Winberg [36], Rashid et al. [37], Sanguankaew and Ractham [44], Venkitachalam and Busch [52]
5	Absorptive capacity: A new perspective on learning and innovation	Cohen and Levinthal [63]	Brachos et al. [27], Cao et al. [39], Sanguankaew and Ractham [44], Pesquita et al. [50], Venkitachalam and Busch [52]
5	The tacit dimension	Polanyi [64]	Benbya et al. [15], Kim et al. [17], Schneckenberg [26], Sanguankaew and Ractham [44], Venkitachalam and Busch [52]
4	An organizational learning framework: From intuition to institution	Crossan et al. [65]	Kim et al. [17], Brachos et al. [27], Rashid et al. [37], Venkitachalam and Busch [52]
4	Dynamic capabilities and strategic management	Teece et al. [66]	Benbya et al. [15], Ordóñez and Lytras [28], Cao et al. [39], Sanguankaew and Ractham [44]
4	Knowledge of the firm, combinative capabilities, and the replication of technology	Kogut and Zander [67]	Brachos et al. [27], Ordóñez and Lytras [28], Roy [40], Gavrilova and Andreeva [47]
4	SECI, Ba and Leadership: A Unified Model of Dynamic Knowledge Creation	Nonaka et al. [68]	Brachos et al. [27], Ahmad and Karim [30], Fazey et al. [42], Rashid et al. [37],

Frequency	Title	Paper	Referenced By
4	Toward a knowledge-based theory of the firm	Grant [69]	Kim et al. [17], Roy [41], Sanguankaew and Ractham [53], Pesquita et al. [50]

In terms of the First Author, there are three papers involving Nonaka at the top of the list of papers commonly surveyed [60,62,68]. This indicates that Nonaka's approach is gaining high attention as a concept for handling knowledge.

2.5. Discussion

Based on the results of the survey, the characteristics and challenges of the KM and KE-based initiatives can be summarized as follows

1) Most of the efforts are at the conceptual level. The targets are related to organizational learning, which is consistent with the aims of KM, and the focus is on sorting, classifying, and interrelating (i.e., organizing) to manage knowledge as an organization.
2) In terms of the content of the initiatives, those related to knowledge creation, analysis, and methods are the most common after organization. In particular, the SECI model and Knowledge Creation [60,62,68] show that this is an area that is attracting attention among knowledge initiatives.
3) There has been no significant progress in the methods for embodying knowledge creation, and traditional methods (Storytelling, Narrative) are mostly used alone or in combination. These are also expensive methods that require both experts and knowledge engineers [47].

In the following, the challenges and solutions for realizing the knowledge creation process based on the concept of organizational knowledge creation for an environment in which humans and computers can create, share, and utilize knowledge on an equal footing are discussed.

2.5.1. The Knowledge Creation Process

The knowledge life cycle model presented by Benbya et al. [15] begins with the knowledge already acquired by the individual and does not discuss the acquisition of knowledge by the individual. As pointed out by Gavrilov and Andreeva [48], the knowledge creation phase has become a challenge for organizational knowledge creation, and considering the situation where no significant progress has been made in a long time, it is necessary to consider the process of knowledge creation and utilization, including the phase of knowledge acquisition by individuals.

Nonaka and Takeuchi [60] present the knowledge creation process as a SECI model consisting of four knowledge transformation modes. In this model, knowledge is classified based on Polanyi [64] into (1) formal knowledge (knowledge that can be communicated through formal and logical language) and (2) tacit knowledge (personal knowledge about a specific situation that is difficult to formalize or communicate to others). The phases in which knowledge is cyclically transformed are also modeled (Table 2.8).

Table 2.8 Phases in which knowledge is cyclically transformed: SECI model [60]

	Phase	Overview
1	Socialization	The process of creating tacit knowledge such as mental models and skills by sharing experiences (multiple people). Tacit knowledge is transmitted and transferred.
2	Externalization	The process of expressing tacit knowledge in a clear concept. Tacit knowledge of oneself, language. Explicit knowledge in the form of metaphors, analogies, concepts, temporary constructions, models, etc.
3	Consolidation	The process of combining concepts to create a single body of knowledge. Create new explicit knowledge by combining different explicit knowledge.
4	Internalization	The process of embodying explicit knowledge into tacit knowledge. Explicit knowledge is embodied through actions and understood and learned as new tacit knowledge. (Learning by doing)

This is highly consistent with the experiential learning model. As described in Kolb [70], the experiential learning model is a four-step learning model based on the idea that people can learn more deeply through actual experience and by reflecting on it. It is a model consisting of cycles (Table 2.9).

Table 2.9 Phases of the experience learning model [70]

	Phase	Overview
1	Specific experience	Have a concrete experience under the person's own circumstances.
2	Reflection	Looking back on one's own experiences from a variety of perspectives.
3	Conceptualization	Generalize and conceptualize so that it can be applied in other situations.
4	Attempt	Try it out in practice under new circumstances.

Based on the previous analysis and existing models of knowledge and learning, a process for organizational knowledge creation is proposed (Figure 2.6).

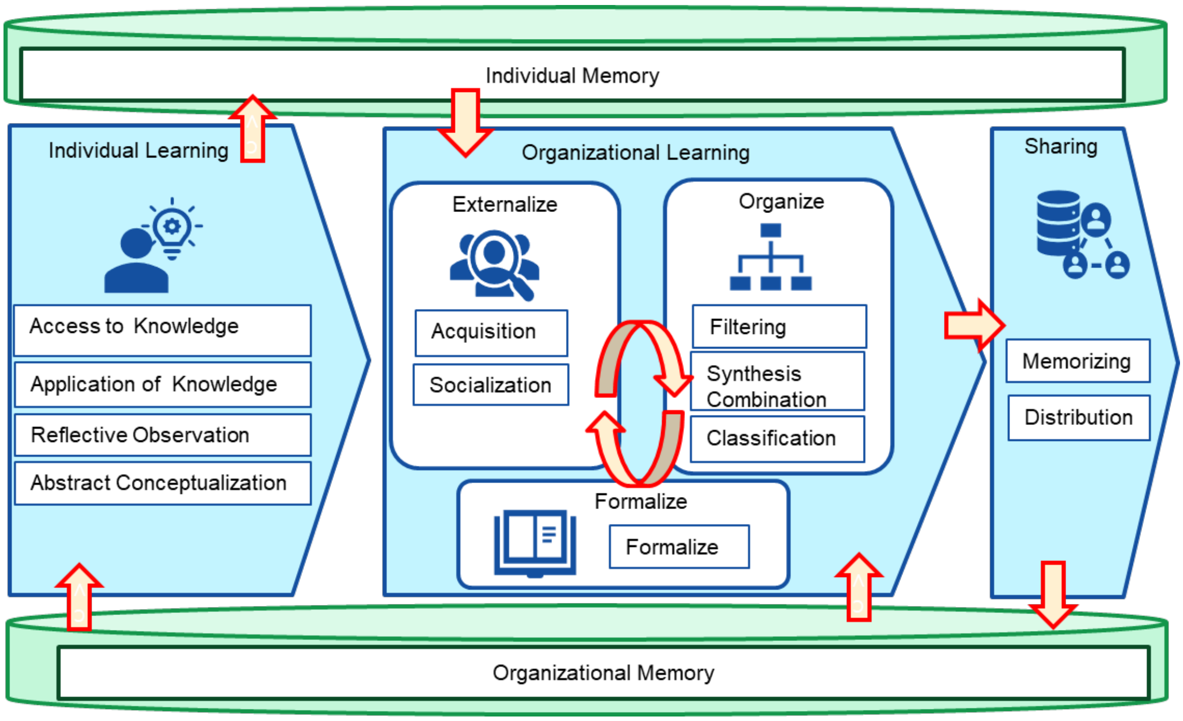


Figure 2.6 The proposed organizational knowledge creation model including individual learning

The process of creating organizational knowledge consists of three stages: (1) individuals use (publicly available) knowledge to gain new experiences and learn from those experiences, and the knowledge resides in the individual (Individual Learning), (2) the organization (small group, company, society) learns (extracts and makes shareable) the knowledge residing in the individual (Organizational Learning), and (3) shares it (Sharing). Organizational learning can be divided into the phases of Externalize-Organize-Formalize, but these phases are not sequential. In the process of spiraling through each phase, learning is considered to deepen (externalization becomes more explicit, generalization increases the scope of application) and to be shared. The outline of each phase is shown in Table 2.10.

Appendix 3 and Appendix 4 categorize the processes, corresponding to Figure 2.6 and Table 2.10 that the main 40 papers and the literature that the main 40 papers surveyed focus on.

Table 2.10 Phases of organizational knowledge creation in the new proposed process

	Phase	Overview
1	Individual Learning	The phase of personalization (learning from experience) by applying an experiential learning model [70].
2	Organizational Learning	The phase in which the knowledge acquired by an individual is acquired as an organization. This phase consists of the following three subphases.
	2a Externalize	Externalize knowledge (Acquisition, Socialization) so that it can be recognized by the organization.
	2b Organize	To handle knowledge as an organization, knowledge is selected, classified, and correlated.
	2c Formalize	Formally express knowledge for recording and sharing.
3	Sharing	Enable knowledge sharing (access to knowledge).

2.5.2. Challenges in Implementing the Proposed Process

By integrating and organizing the results of KM and learning models, a new process model for creating organizational knowledge has been defined. However, the actual creation and utilization of knowledge is not always executed as a linear process, and it is necessary to consider that each phase is executed in a spiral manner, like the spiral model versus the waterfall model in the software development process. In addition, in order for everyone to be able to handle knowledge, it is necessary to develop tools and services that can be used by end users. However, the process of knowledge creation and utilization is assumed to be mediated by knowledge experts (experts in each field, knowledge engineers, educators, etc.), and is not sufficiently supported by computer/software systems. Under these circumstances, the following efforts are needed to evolve the creation and utilization of knowledge in the future.

1) Adequate theories, methods, and tools that can be used by everyone are difficult to achieve from KE perspective alone (as has been the case in the past). Integration/cooperation of knowledge across domains/fields is necessary.
2) Collaborative efforts in the fields of SCM, distribution, medical care, agriculture, and Smart Service (AI) have been conducted mainly by KM. There are few bridging activities (research) such as discussions and collaborative efforts between KE and KM, which are the most related areas, and there are no significant results. It is necessary to integrate KE and KM, including technical cooperation related to knowledge acquisition and knowledge elicitation, such as the method that embodies the above-mentioned externalization.
3) By integrating KE and KM with research from the perspective of human-AI co-creation, such as Human-AI Collaboration and Human-Centered AI, computers can be added to the existing knowledge creation by humans and humans. By using a virtual space, it can hopefully reduce the need for direct communication in the same space at the same time. In addition, by effectively utilizing the processing and learning capabilities of computers, it is possible to efficiently conduct communication and knowledge creation activities between a wide range of diverse people.
4) For people and computers to collaborate in knowledge creation, it is necessary to design and implement knowledge representation formats and interfaces that enable people and computers to communicate and understand each other's knowledge.
5) In addition, as in the case of KM in environmental issues (sustainability), it will be necessary to collaborate with a wider range of business and academic fields.

2.5.3. Requirements for Knowledge-Centered Human-Computer co-Creation

Based on the above discussion, the requirements for knowledge-centered human-computer co-creation are summarized below.

1) Knowledge in an organization is formed through the phases of (1) individual learning, (2) organizational learning - (2a) externalization, (2b) organization and association, (2c) formalization, and (3) sharing. These phases are not carried out in a sequential manner as in a waterfall, but rather in a spiral process.

2) To enable an organization to use knowledge to guide decisions and actions, it is not enough to communicate knowledge as instructions or procedures (rules and norms). It is necessary to share it in relation to what underlies it (rationale and reasons, purpose and intent) [71]
3) The conventional approach of extracting, organizing, and formalizing the knowledge acquired by individuals has difficulties in extracting tacit knowledge. An approach in which individuals record their knowledge acquisition, including its rationale and purpose, is thought to be effective.
    a) The problem of knowledge transfer by knowledge holders to other people and organizations has already been recognized as a costly challenge for knowledge base creation in the development of expert systems. In KM, approaches such as the environment (Ba) for transferring tacit knowledge [60], where the transfer takes place in a collaborative process between the knowledge holder and the person who inherits the knowledge, have been presented. Both of these approaches require the presence of experts, learners, knowledge engineers or managers of the collaboration in the same time and space, and there is a high associated cost.
    b) The disconnection between individual learning and organizational learning is mainly due to the fragmentation among learning theory, KE, and KM (lack of coordinated efforts). Therefore, solutions from a cross-disciplinary perspective are required.
4) For everyone to be able to generate high-quality knowledge, it is necessary to support the knowledge creation process with a tool or service, e.g., a software system. This software system needs to support (1) a structure for representing knowledge in relation to its underlying rationale and reasoning as well as its purpose and intent, (2) specific interactions (interactions) between humans and the software system for handling the content corresponding to the structure of knowledge (items that constitute knowledge), and (3) interfaces (input methods, visualization methods) that support the understanding and creation of knowledge through interaction. In addition, in order to maintain a knowledge creation process that is flexible to changes in the environment and circumstances, (4) quality indicators and evaluation of knowledge creation activities are also necessary to monitor the collaborative activities of people and computers and to determine the need for improvement.

2.6. Issues to be Solved

The purpose of this chapter was to systematically review efforts in KM and KE that can be utilized in designing human-computer co-creation, and to present the design requirements for an environment in which humans and computers can create, share, and utilize knowledge on an equal footing. KM is an approach to share and utilize the knowledge acquired by individuals as an organization (creation of organizational knowledge). KM is complementary to KE, which is an approach for knowledge acquisition (learning) by individuals and knowledge representation on computers. By combining these approaches, it is expected to realize an environment where humans and computers can engage in creative activities on an equal footing through knowledge-centered collaboration between humans and computers.

The design requirements for a knowledge-centered co-creation environment are summarized below.

1) Support for structures for expressing knowledge in relation to the underlying rationale and reasoning and purpose and intent.
2) Support for specific interactions between people and software systems to handle content (items that constitute knowledge) that corresponds to the knowledge structure.
3) Support for interfaces (input methods, visualization methods) that support understanding and creation of knowledge through interaction.
4) To maintain a knowledge creation process that is flexible to changes in the environment and circumstances, define quality indicators for knowledge creation activities, monitor collaborative activities between humans and computers, and determine the need for improvement.

KM is a way of thinking that is related to a wide range of knowledge-related fields, and it is expected to solve knowledge-related issues through individual efforts in knowledge management and collaboration with other approaches represented by KE. Therefore, it is necessary to relate and incorporate each elemental technology while being aware of the overall picture of KM. Design, trial, and evaluation of software systems based on the design requirements for a knowledge-centered human-computer co-creation environment can be considered as the next work. In addition, it is appropriate to continuously work on improving knowledge structures, representation methods, algorithms, and interfaces in order to increase the efficiency and accuracy of knowledge utilization.

Chapter 3

Preliminary Design, Implementation, and Analysis for Knowledge Creation Environment

In this chapter, the design, implementation, and evaluation of the knowledge-creating environment based on the design requirements of the knowledge driven human-computer co-creation environment are discussed, and the insights for deriving the design method for software systems is shown. Focusing on the knowledge creation activities of curators in the museum, an attempt was made to design and implement a software system that supports the activities. Then, through its evaluation, necessary requirements on the method for designing a knowledge-driven collaborative environment for human-computer co-creation is derived.

3.1. Smart Museum

The system that supports and improves knowledge creation activities based on data from sensor networks aims to understand the experience of visitors at the museum and to gain findings and learning of improvement. The lessons learned from the visitor's experience at the museum can be interpreted in two different contexts: the visitor and the curator. For curators, learning involves understanding the behavior/reactions of visitors to improve the museum experience through the curator's learning. The proposed system is designed to perform passive measurements to capture data about the movement of visitors on the exhibition hall along with various environmental data. The role of the system is to support curators in investigating, reasoning, and correlating data, and ultimately to the generation of useful knowledge that can be shared with colleagues. Currently, the observation components of the system are being developed, data is being collected daily at affiliated museums, and data exploration and knowledge creation environments are being developed for curators.

3.2. Related work

3.2.1. Knowledge-Based Engineering

Efforts to use knowledge to improve the quality of activities have been carried out in the field of Knowledge-Based Engineering (KBE). Verhagen et al. [72] organizes and evaluates KBE-related efforts and presents research agendas. KBE is a field of research methodologies and techniques for acquiring and reusing product and process engineering knowledge, to reduce product development time and costs. This is primarily achieved by automating iterative design tasks while acquiring, retaining, and reusing design knowledge. KBE's challenges include:

1) Ad hoc development: Developers need to identify issues and create individual KBE solutions based on a custom development process.
2) Black box application trends: Knowledge cannot be reused due to a lack of provisions for

capturing design intent, formulas for captured knowledge, and explanations of actual meaning and context.

It has been proposed to introduce methodologies/frameworks, ensure transparency of KBE applications, strengthen knowledge model semantics and their traceability, and promote effective procurement and reuse of knowledge as directions for solving these problems. A specific initiative is a platform called the Smart Innovation Engineering (SIE) system [73]. It incorporates SOKES, DDNA [74,75] into KBE, adding knowledge collection and reuse to leverage empirical knowledge in decision making that incorporates IoT and CPS. DDNA and SOEKS are initiatives related to the expression of empirical knowledge. Using these, attempts were made to implement a computer framework that discovers, stores, adds, improves, and shares information and knowledge among machines, organizations, and decision-makers through experience, and makes decisions incorporating IoT and CPS. It has been proposed to utilize empirical knowledge [74].

SOEKS is a domain-independent standardized knowledge structure that aims to capture formal decision-making events in a dynamic format and store them as explicit empirical knowledge for later use. In SOEKS, empirical knowledge is accumulated by combining four basic components: variables (V), functions (F), rules (R), and constraints (C). Decision DNA (DDNA) is a knowledge representation (KR) approach that compares this to what human DNA does and inherits knowledge related to decision-making in the future [74]. SOEKS and DDNA have been reported to be applied to financial forecasting, data mining, Alzheimer's disease diagnosis, embedded systems, robot path planning, numerous engineering processes, engineering designs, neural networks, deep learning, etc. [12]

SOEKS, DDNA, targets activities that have a clear process of decision-making, as shown in a series of references [74-76]. Therefore, it is possible to define rules and constraints for the possible values (called variables in SOKES and DDNA) as a result of the decision. Moreover, it is possible to determine in advance the function (called a function in SOKES, DDNA) that acts on the variable (result of the decision). In cases where there are no clear criteria or there are various criteria, it is necessary to respond according to the context of the decision, and it is difficult to define functions that act on rules, constraints, and variables in advance.

3.2.2. Domain-Driven Design

Domain-Driven Design [77] is a method that incorporates the use of knowledge into software system design. Domain-Driven Design (DDD) can be regarded as a method that incorporates the concept of KBS into the object-oriented design, which is a software system design method. By incorporating the business rules in the business area (activity area) into the object, the business is realized on the software system. DDD presupposes that business rules can be decided in advance, but in today's diversified values, it is necessary to make business decisions according to the situation. In other words, it is necessary to change the rules to be applied from the viewpoint of business strategy (that is, purpose and intention in the business decision) under the situation. In areas where the process is clear as a business activity and the decision-making criteria are clear (or can be clarified), efforts are underway to capture and utilize the experience related to decision-making in business activities as knowledge on a computer. More flexibility is needed in cases where the value criteria are not always clear, or where the criteria need to change (or may change) depending on the context of the activity [5].

In this way, in the field related to manufacturing (engineering), efforts to incorporate knowledge are being made continuously, centering on experiential knowledge, but the purpose and intention can be judged to be automation. In other words, it is to improve activity efficiency by making decisions such as choices and decisions made by experts into knowledge as data, rules, and procedures so that anyone can automatically execute them. The problem with automation is that it becomes difficult to understand and pass on knowledge, as pointed out by the above-mentioned black-boxing of operations [72] and discussions on the explanation of AI [2,3]. In addition, the black-boxing that accompanies automation can prevent one from changing and editing rules and standards as the situation demands, making it impossible to respond appropriately. To ensure reliability, safety, and trustworthy in the collaboration between computers and humans, it is necessary to balance automation and human control [1]. Therefore, there is a need to shift to sharing and using knowledge for the creation of new knowledge (learning and findings of the actors themselves) rather than knowledge for automation. Specifically, it is to achieve the following.

1) A format of knowledge to maintain an understandable and editable state, not a realization of automation.
2) An environment in which such knowledge is appropriately selected and applied in activities, new experiences are carried out, and knowledge (learning and findings) is acquired as knowledge-based interactions.

The knowledge creation support environment proposed in this work focuses on the structure of knowledge and the operations for handling knowledge, focusing on understandable and editable. And knowledge creation examples based on the data collected show that this design reuses knowledge and promotes knowledge creation. In addition, the framework derived from the discussion of results provides useful insights on how to design systems that facilitate knowledge creation.

In the following, the knowledge creation activities of curators will be analyzed, and the design of the environment to support the knowledge creation activities of curators will be shown. Next, an example will be introduced in which the environment supports the knowledge creation activities of curators using the data collected. Then, based on the results, consideration is given to the environment that supports knowledge creation.

3.3. Method: Design of Curator's Knowledge Creation Activities and Support Environment

It can be expected that the curator at the museum will use digital technology to collect the reactions of visitors and improve the design of the exhibition to provide a more satisfying museum experience [78]. Understanding the museum experience of visitors and gaining findings and discoveries is one of the important knowledge-creating activities of curators. Below, the activities of curators to collect the reactions of visitors and improve the design of the exhibition (hereinafter referred to as curator's knowledge creation activities) are analyzed. Then, the requirements required for the environment that supports the curator's knowledge creation activities (hereinafter referred to as the support environment) are organized, and a model of the support environment is presented.

3.3.1. Analysis

1) Process: The curator's knowledge creation activities can be broken down into the following processes.
   a) Collect: Collect the viewing experience of visitors.
   b) Explore: Understand the collected viewing experiences and gain findings and discoveries about the exhibition.
   c) Donate: Share the findings and discoveries gained as organizational knowledge.
   d) Execute: Execute improvements based on findings and discoveries.
2) Actor: There are curators and visitors as actors in the curator's knowledge creation activity process. The intent of the curator's activities in this process is to understand the viewing experience of the visitors and to gain findings and discoveries that will lead to improvements in the exhibition design. To understand the collected viewing experience and gain findings and discoveries, it is necessary to visualize and interpret (appreciate) the collected information from various perspectives by trial and error. This is the same activity as exploratory data analysis. However, curators are not necessarily experts in data analysis, so they need to be able to perform such activities based on their knowledge of museum exhibition design, without the need for special data analysis knowledge.
   Visitors' activity intention is to appreciate the exhibits. This visitor can be divided into those who are willing to spend time watching (engaged) and those who are not (casual) [79,80]. Casual visitors make up the majority compared to engaged [81]. Until now, the content of the viewing experience of visitors has generally been conducted by questionnaire surveys. However, it is difficult to get answers from casual visitors, and it is necessary to collect viewing experiences that do not rely on active involvement. Furthermore, when collecting viewing experiences, care must be taken not to infringe the right to protect personal data represented by the GDPR (General Data Protection Regulation).

3.3.2. Requirements

Based on the results of the analysis, organize the requirements of the support environment.

1) Collection of viewing experiences.
   a) Do not require the active involvement of visitors.
   b) Do not infringe the right to protect personal data.
2) Exploration and analysis of collected viewing experiences
   a) Can be visualized and interpreted (appreciated) by trial and error from various perspectives.
   b) Can be carried out based on knowledge of exhibition design in museums without the need for special data analysis knowledge.

3.3.3. System model

The system model was designed as shown in Figure 3.1 based on the requirements.

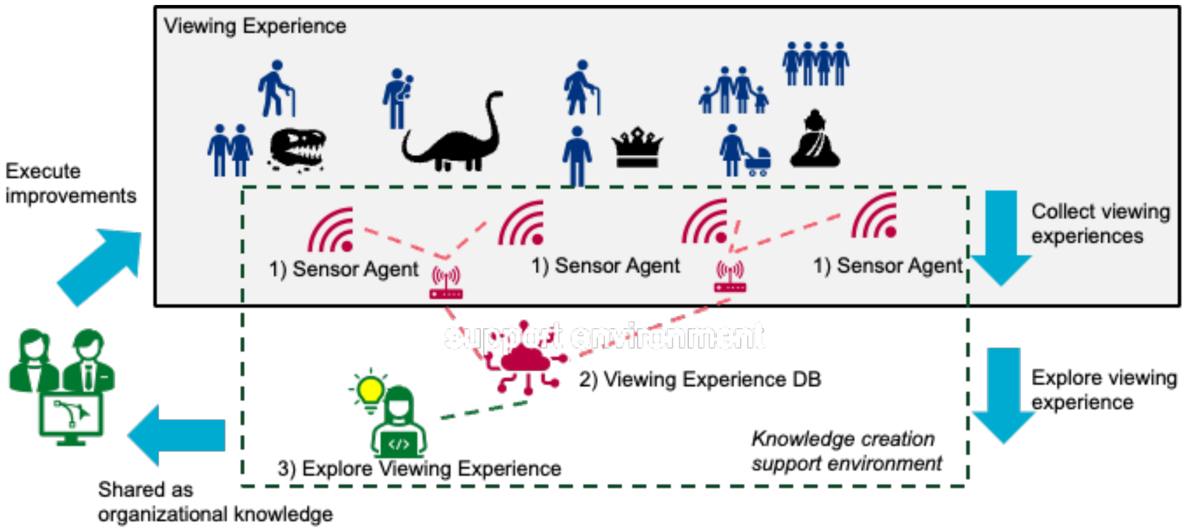


Figure 3.1 Curator's knowledge creation activities and support environment

The support environment consists of 1) a sensor node that collects viewing experiences, 2) a viewing experience database, and 3) a search/analysis function for viewing experiences (by a curator).

1) Sensor Agent: A sensor network consisting of multiple sensor agents will be introduced in the exhibition room as a way to collect viewing experiences without relying on active involvement. Individual sensor agents detect and record visitors who are viewing at that location. It also measures and records the conditions of the viewing environment such as temperature and humidity at that time. In sensing and recording, in consideration of the right to protect personal data, information such as images and sounds that can identify individuals is not saved, and access from the outside is also blocked.
2) Viewing Experience DB: Accumulates the viewing experience collected by the Sensor Agent and makes it available for curators to explore and analyze. To help curators explore and analyze from multiple perspectives on a trial and error basis, datasets for viewing experiences, methods for visualizing datasets, and methods for manipulating datasets are also shared.
3) Explore Viewing Experience: Explore and analyze the viewing experience using the datasets and methods shared by the Viewing Experience DB.

The shared dataset retains the structure shown in Viewing Experience in Figure 3.2 as a template for the information that represents the viewing experience. The viewing experience is expressed as information sensed at a certain date and time (DateTime) at a place in the exhibition hall (area sensed by the sensor agent). For example, Visitors will appreciate it at the sensor agent (the area that it senses) at 15:00 on July 16, 2021. The sensor agent and its location are independently associated. It is necessary to install and analyze and adjust the acquired data to determine what kind of sensor should be placed in the exhibition room of the museum and in what position to obtain an appropriate impression experience. However, the structure is such that the measurement accuracy of the sensor agent can be improved, and the curator can search and analyze the viewing experience independently and in parallel.

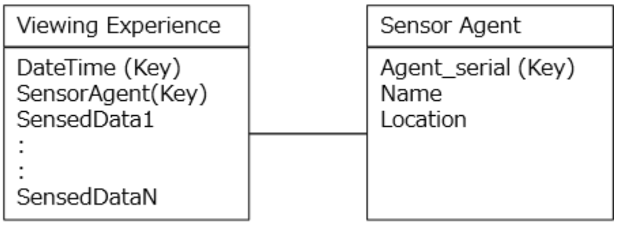


Figure 3.2 Information Structure of Viewing Experience

The support environment provides the functions of a correlation graph that visualizes the relationships between data and a time series graph that visualizes time-series trends according to the structure of the viewing experience. Furthermore, by visualizing the place where the appreciation was performed, it is possible to support exploration and analysis of differences in the viewing experience depending on the contents of the exhibition. To search and analyze from multiple viewpoints, it is also necessary to operate the data set. It provides a function to change the time particle size of data (zoom: aggregate by day, hour, minute), and to change the range of target data (scope: select data of a specific period, time zone, sensor node). It also provides the ability to record and share findings and discoveries obtained as a result of exploration and analysis. The important thing in sharing and providing these datasets and methods is that the curators who are the users can understand each other. What's more, they can be arranged and new datasets and methods can be created using previously created datasets and methods. For that purpose, it is necessary not only to share and provide instructions and procedures (procedures, rules, and norms) but also to relate them to the underlying (grounds, reasons, purposes, intentions) [71]. Therefore, items such as intent, purpose, constraint, and generation method are added and maintained as metadata for the dataset or method.

3.4. Result

The prototype system was introduced into the museum and started trial operation as shown in Figure 3.3. Eleven Sensor Agents are placed in the exhibition room of the museum, and the data from each Sensor Agent is sent to the DB server installed at the University of Aizu (UoA) via the mobile LTE network. And it is used for exploration and analysis of viewing experience as a knowledge creation activity of curators.

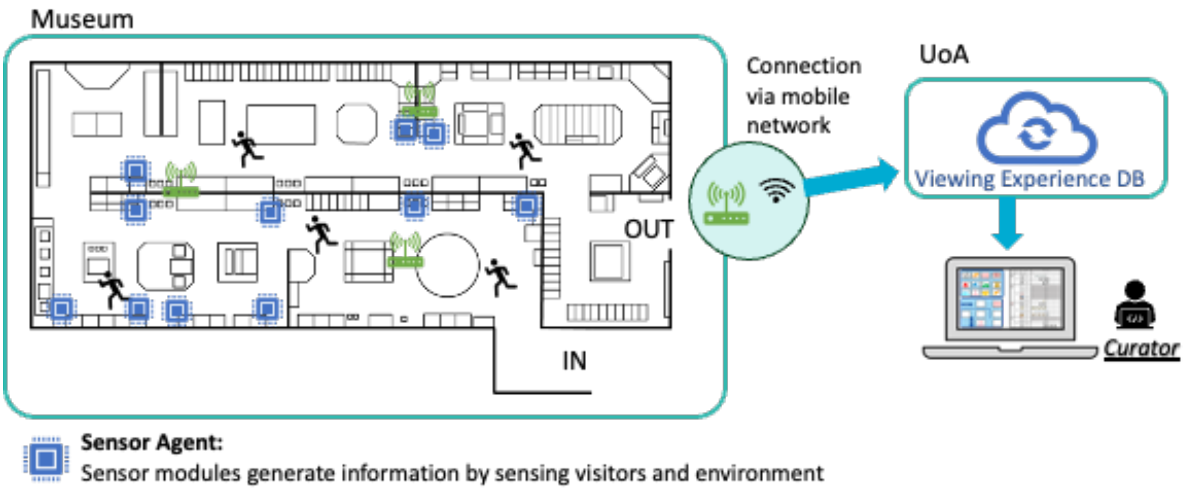


Figure 3.3 Overview of the system installed in the museum

3.4.1. Sensor Agent

A network of passive sensing modules has been developed to observe visitor behavior using a collection of sensors such as PIR（Passive Infrared Ray）Motion Sensor, cameras, and thermography. Sensors measure visitor behavior and environmental changes at stationary monitoring points to statistically estimate visitor behavior (Figure 3.4). The module is built from a set of sensors and a Raspberry PI board. They were designed and built by researchers to meet the museum's requirements.

This design runs Yolo on a sensor module rather than a server/cloud. The main reason is to keep the system simple and cost-effective by using affordable and generally available components. Also, by performing the computations on the sensor modules, it is possible to avoid transmitting/storing images, including personal data, over the network. This design and implementation assume step-by-step optimization based on evaluating measurement results. When evaluating and improving data measurement methods, it is expected to consider and improve the balance between edge processing and cloud processing based on actual needs and limitations.

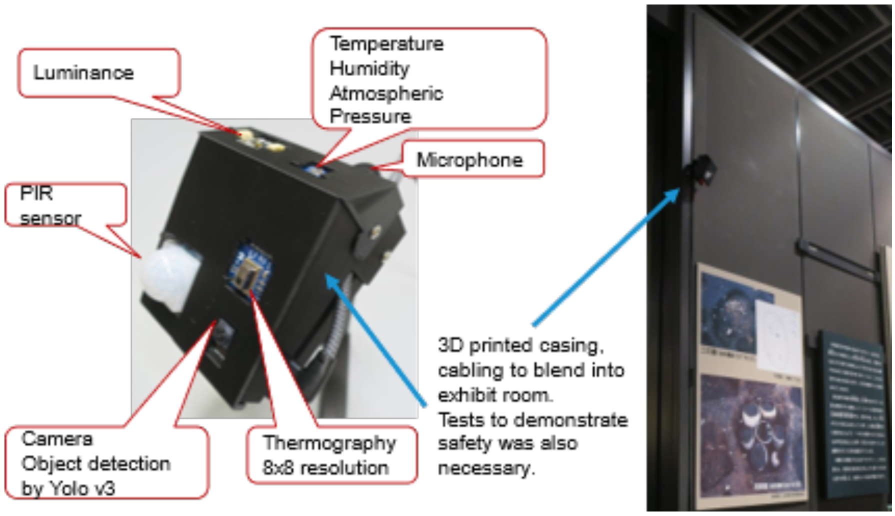


Figure 3.4 Overview of Sensor Agent

This module measures eight values, three of which are for observing visitor behavior, movement (PIR), number of people (camera + object detection), and congestion (thermography). Three sensors on visitor behavior are arranged to experiment with their different functions and how they can complement each other.

3.4.2. Viewing Experience Database

Viewing Experience Database (DB) consists of two types: datasets and methods. For datasets and methods, items such as intent, purpose, constraint, and generation method related to them are added and maintained as metadata. In the prototype system, to analyze the detailed requirements of the function to search and analyze the viewing experience, the search and analysis function is prototyped using the exploratory data analysis environment R. For this reason, the implementation as a DB is currently based on the R specifications, but in the future, it will be implemented as a DB independent of the search and analysis tools.

1) Datasets: The basic data set is MeXDS (Museum Experience Dataset), which expresses the viewing experience (visitor behavior and viewing environment) based on the data measured once a minute by the sensor agent. In addition, the results of the operations performed during the curator's search and analysis process are also shared and added to the dataset. The items that make up MeXDS are in Table 3.1.

Table 3.1 MeX Dataset structure representing the viewing experience

Name	Device	Intention of measurement	Measurement-Method
time	System time	Data collection date and time	The sensor agent records the time when the data was measured.
agent_serial	Sensor Node	Uniquely identify the sensor agent	The unique number (serial number) of the sensor agent is added at the time of data transmission.
temperature	Temperature sensor	Temperature (celsius)	Temperature sensor measurements (measured at 1-minute intervals)

Name	Device	Intention of measurement	Measurement-Method
humidity	Humidity sensor	Humidity (%)	Humidity sensor measurements (measured at 1-minute intervals)
pressure	Barometric pressure sensor	Atmospheric pressure (bar)	Barometric pressure sensor measurements (measured at 1-minute intervals)
luminance	Illuminance sensor	Illuminance (lux)	Illuminance sensor measurements (measured at 1-minute intervals)
noise.db	Microphone	Loudness (dB)	The loudness of the sound picked up by the microphone. (The collected data is not saved, and conversations are not recognized or recorded.)
motion	PIR motion sensor	Probability of having people (%)	It measures once every 0.5 seconds with a motion sensor and calculates the probability of detecting movement in 1 minute.
presence	Camera	Number of people	Calculate the number of people included in the captured image. (Only the person is judged by machine learning, and the individual is not identified.)
pXm	Program	Number of people detected (expected value)	The product of the estimated number of people (presence value) based on image recognition and the probability that there are people (motion value) was calculated as the expected value.
nvis	Person	Number of visitors per day	The museum staff counts the number of visitors every day.

Table 3.2 Overview of Visualization methods

Method	Intention	Input	Example
MeXpl	Graph by specifying the period (tdt-> tdt) for the two item names (x, y) of the specified data set (sDS) (no agent layer classification)	MeX datasets	MeXpl(sDS=MEXDS, x=”time”, y=”pXm”, fdt="2021-06-19", tdt="2021-07-03") For the data of MeXDS from June 19th to July 3rd, 2021, set the x-axis to time and the y-axis to pXm and draw a correlation diagram.
MeXpl.a	For the two item names (x, y) of the specified data set (sDS), specify the period (tdt-> tdt) and agent, and graph by stratification by agent.	MeX datasets	MeXpl.a(sDS=MEXDS, x=”time”, y=”pXm”, fdt="2021-06-19", tdt="2021-07-03") For the data of MeXDS from June 19th to July 3rd, 2021, set the x-axis to time and the y-axis to pXm and draw a correlation diagram. Allows identification for each Agent.
MeXpl.t	For the item name (y) of the specified data set, specify the period (tdt-> tdt) and agent and graph by stratification on a daily basis.	MeX datasets	MeXpl.t(sDS=MeXDS, fdt="2021-06-19", tdt="2021-07-03") For the data of MeXDS from June 19th to July 3rd, 2021, set the x-axis to time and the y-axis to pXm and draw a correlation diagram. Compare the changes in the same time zone on each day.

2) Visualization method: The correlation graph for visualizing the relationship between data items and the time-series graph for visualizing changes and trends over time are provided as methods (Table 3.2). Furthermore, by visualizing the place where the appreciation was performed (Sensor Agent), it is possible to support exploration and analysis of differences in the viewing experience depending on the contents of the exhibition.
3) Dataset operation method: Focusing on the data key, the function to change the time particle size of the data (zoom: aggregate by day, hour, minute), and the function to change the range of the target data (scope: targeting specific periods, time zones, and sensor agents) are provided as methods (Table 3.3).

Table 3.3 Overview of Dataset operation methods

Method	Intention	In Out	Example
MeXsum.at	Aggregate MeX datasets by date and time and Agent by key. The interval is specified in seconds.	MeX dataset	MeXsum.at(interval=60*60, sDS=MeXDS, fun=mean) MeXDS (1 minute value) is aggregated into 1 hour value for each Sensor Agent using the average value for 1 hour (60 seconds x 60 minutes). "
MeXsum.t	Aggregate MeX datasets by date and time. The interval is specified in seconds.	MeX datasets	MeXsum.t(interval=60*60, sDS=MeXDS,) MeXDS (1 minute value) is aggregated into 1 hour value using the average value for each hour (60 seconds x 60 minutes) throughout the museum.
MeX.SelectOpenHours	Extract museum opening hours data from the MeX dataset.	MeX datasets	MeX.SelectOpenHours(sDS=MeXDS, fr="09:30:00",to="17:30:00") Extract data on opening hours (9: 30-17: 30) from MeXDS every day. "
MeXtrange	Extract Agent data as a dataset for a specified period from the dataset	MeX datasets	MeXtrange(fdt="2021-06-19", tdt="2021-07-03", sDS=MeXDS, agent=Agent) Extract data corresponding to the Agent from the data of the period (2021/6 /19- 2021 /7/3) from MeXDS.

3.4.3. Exploration and analysis of viewing experience

The curator's exploration and analysis of the viewing experience begins with an overview of the shared datasets and methods. Then, after previewing the dataset, visualization is performed while aggregating the data and selecting the range, triggered by interests, doubts, findings, and discoveries. In addition, as findings and discoveries are gained, they are shared with colleagues. In the following, along with this scenario, an example of exploring and analyzing the viewing experience using datasets and methods is shown. For the example, the data measured between June 19, 2021, and July 3, 2021, is used.

1) Overviewing of datasets and methods: Figure 3.5 is an overview of the dataset provided to the curator. a is the information of the items that make up the dataset, b is the map of the location where the sensor agent is installed, and c is the installation information of each sensor agent. The dataset information described in Table 3.1 can be referenced at any time during exploration and analysis. Similarly, information on the methods described in Table 3.2 and Table 3.3 is also provided.

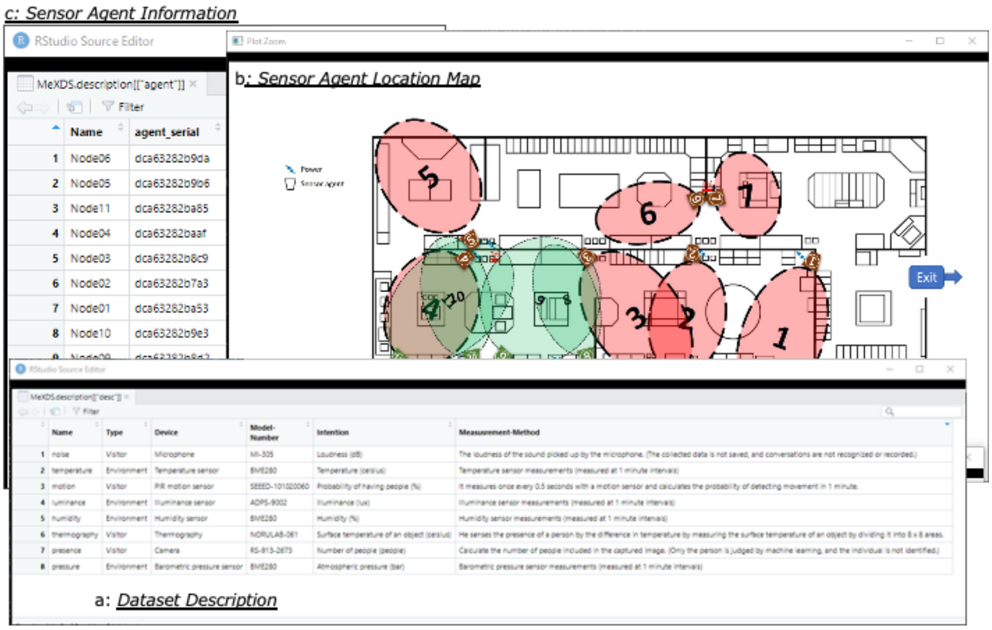


Figure 3.5 Dataset information for curators

2) Dataset preview： First, graph the pXm (expected value of the number of people detected by the sensor) of the data set (MeXDS) using the visualization method (MeXpl) and give an overview of the whole Figure 3.6. However, since MeXDS is 1-minute value data measured by 11 Sensor Agents, there is too much data to interpret. Therefore, the curator considers counting the estimated number of people per day.

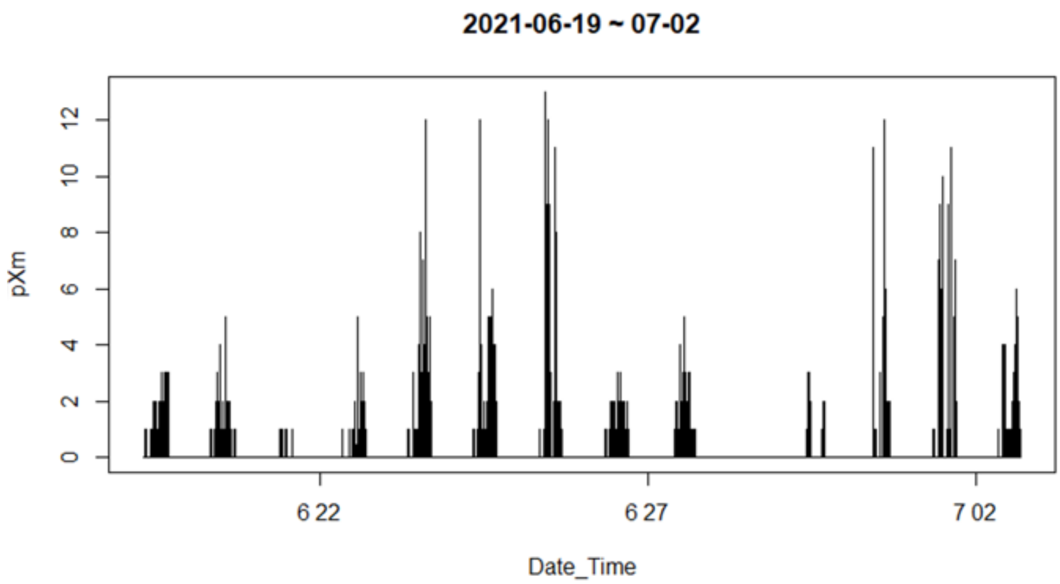


Figure 3.6 Simply graph pXm using MeXDS

3) Dataset aggregation and visualization of aggregation results: Aggregation uses the method MeXsum.at. By looking at the location map of the sensor agents (Figure 3.5b), some sensor agents can notice that the sensing ranges overlap. Therefore, the idea of selecting the Sensor Agent with less overlap of the sensing range and totaling the estimated number of people per day for the 7 Agents is derived. Using the aggregated data set, the estimated number of people per day (pXm) detected by the sensor agent and the number of visitors per day (nvis) aggregated by the museum are graphed and compared (Figure 3.7).

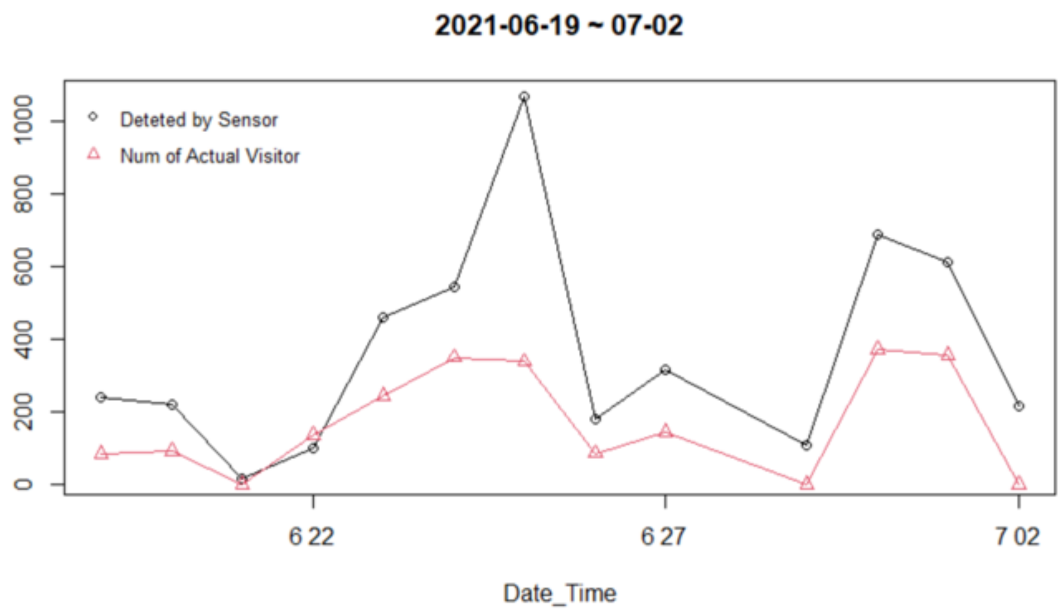


Figure 3.7 Comparison of daily visitors and actual visitors

The estimated number of people per day (pXm) detected by the sensor agent exceeds the number of visitors per day, but the reason is that visitors may watch at the same place for multiple minutes or more. It can also be read that the pXm value is almost linked to the number of visitors per day. From this, it is noticeable that the number of visitors can be compared by time zone and place (Sensor Agent's sensing range) using the pXm value.

4) Findings and sharing: By comparing the difference in the number of people detected depending on the location (sensor agent), it is possible to compare the difference in how visitors gather. Aggregate as before and graph using the Mexpl.a method so that you can see the differences for each sensor agent (Figure 3.8).

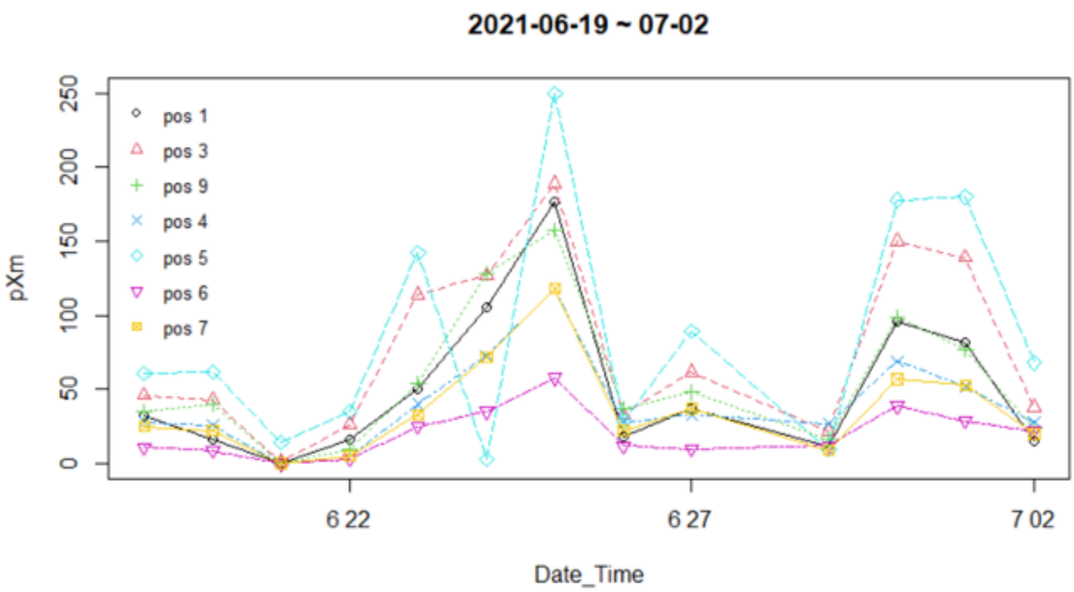


Figure 3.8 Number of visitors in places (sensor agents)

From this graph, it can be seen that the sensing range of sensor agents pos5 and pos3 is always at the top regardless of the day as the difference in the gathering of visitors depending on the location. Then, it is possible to realize that it is worth conducting further exploration and analysis when considering exhibition planning, such as investigating the relationship between the exhibition contents and exhibition methods at pos5 and pos3. Also, on June 24th, the value of pos5 tends to be different before and after, indicating that the sensor agent may have been turned off. Such findings can be recorded and shared as shown in Figure 3.9. Image is used not only to show the basis of findings in an easy-to-understand manner, but also to show the intention of search and analysis, which is the process leading to findings, and the method used. As a result, the person who refers to the shared findings can perform the same operation by oneself and can arrange this to perform a new search/analysis.

In this way, the curator can search and analyze the viewing experience of visitors from multiple perspectives by aggregating the dataset and extracting the range by oneself. Then, the result of the data set operation performed in the process is shared as well as the findings. The contents of the sharing are as shown in Table 3. 4. It is not just a brief overview of the dataset, but also includes intent and examples of the manipulation and visualization methods used to generate it, helping other curators to use and apply it.

Table 3. 4 Example of generated and shared dataset

Name	**Intention**	**Creation Method**	**Visualization example**
MeXDS	Original data	read_excel("DS20210702.xlsx")	MeXpl(sDS=MeXDS, x="time", y="pXm")
MeXDS.at	1-minute value data (key: date and time & Agent)	MeXsum.at(interval=60, sDS=MeXDS)	MeXpl.a(sDS=MeXDS.at, x="time", y="pXm")
MeXDS.t	1-minute value data (key: date and time)	MeXsum.t(interval=60, sDS=MeXDS)	MeXpl.t(sDS=MeXDS.t , x="time", y="pXm"")
MeXDSopn .at	Extract only opening time data (key: date & time & Agent)	MeXsum.at(interval=60, sDS=MeX.SelectOpenHours(sDS=MeXDS, fr="09:30:00",to="17:30:00"))	MeXpl.a(sDS=MeXDSopn.at, x="time", y="pXm")
MeXDSopn .t	Extract only opening time data (key: date and time)	MeXsum.t(interval=60, sDS=MeX.SelectOpenHours(sDS=MeXDS, fr="09:30:00",to="17:30:00"))	MeXpl(sDS=MeXDSopn.t, x="time", y="pXm")
MeXDS24 H7.at	For Sensor Agents (1,3,9,4,5,6,7) with little overlap of sensing ranges, the estimated number of people per day is totaled (key: date and time & Agent)	MeXsum.at(interval=60*60*24, sDS=MeXtrange(sDS=MeXDS.at, fdt="2021-06-19", tdt="2021-07-03", agent=Agent[c(1,3,9,4,5,6,7),]))	MeXpl.a(sDS=MeXDS24H7.at, x="time", y="pXm")
MeXDS24 H7.t	For Sensor Agents (1,3,9,4,5,6,7) with little overlap of sensing ranges, the estimated number of people per day is totaled (key: date and time)	MeXsum.t(interval=60*60*24, sDS=MeXtrange(sDS=MeXDS.at, fdt="2021-06-19", tdt="2021-07-03", agent=Agent[c(1,3,9,4,5,6,7),]))	MeXpl(sDS=MeXDS24H7.t, x="time", y="pXm")

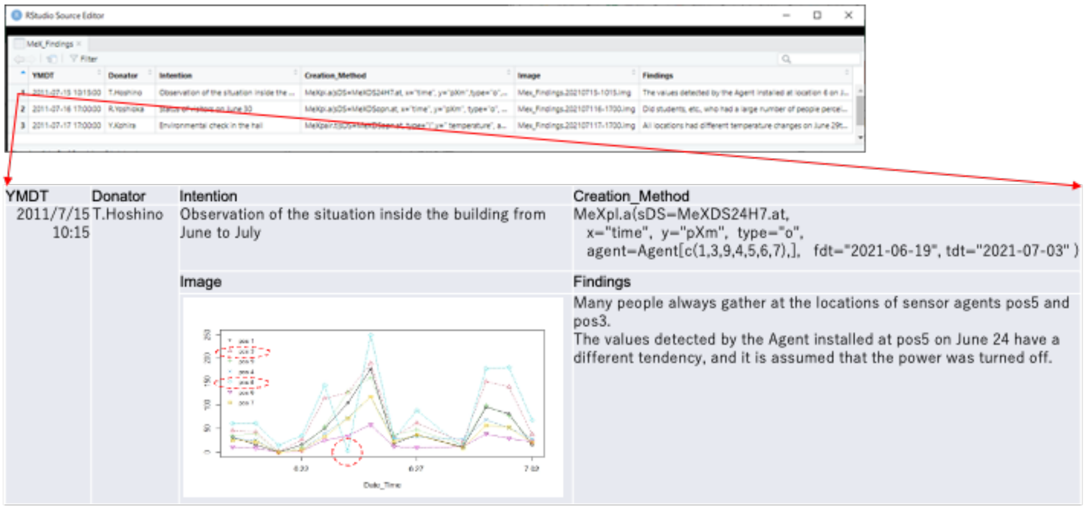


Figure 3.9 Recorded and shared findings and discoveries

From the examples introduced so far, it can be seen that the environment designed based on the concept of knowledge experience can support the knowledge creation activity of exploration and analysis of the viewing experience of visitors by curators.

3.5. Discussion

From the examples introduced so far, it can be seen that the environment designed based on the concept of knowledge experience can support the knowledge creation activity of exploration and analysis of the viewing experience of visitors by curators. Designing based on the concept of knowledge experience begins with analyzing and understanding the process of the target activity and the nature of the Actor involved in the process. In this case, it was an activity to improve the contents of the exhibition from the reaction (viewing experience) of the visitors of Curator. This basic process can be modeled as Collect, Explore, Donate. Collect is a measurement of the viewing experience of visitors. The measurement needs to be designed based on constraints such as the nature and location of the actor. Explore is an exploration and analysis of the viewing experience of visitors. In exploration and analysis, not only datasets but also methods for manipulating information need to be shared as understandable and applicable information. And Donate is the sharing of knowledge as an organization. By sharing information and manipulation methods as understandable and applicable information, it can be expected that other curators will reuse it and lead to new knowledge. These activities, in the form of improving exhibitions, create value for sharing newly created knowledge with visitors. Based on the contents so far, the framework of the knowledge creation environment is derived. In this framework, Actors such as people and sensors act as Agents through the Knowledge Creation Interface and collaborate centering on Active Knowledge to create knowledge (Figure 3.10).

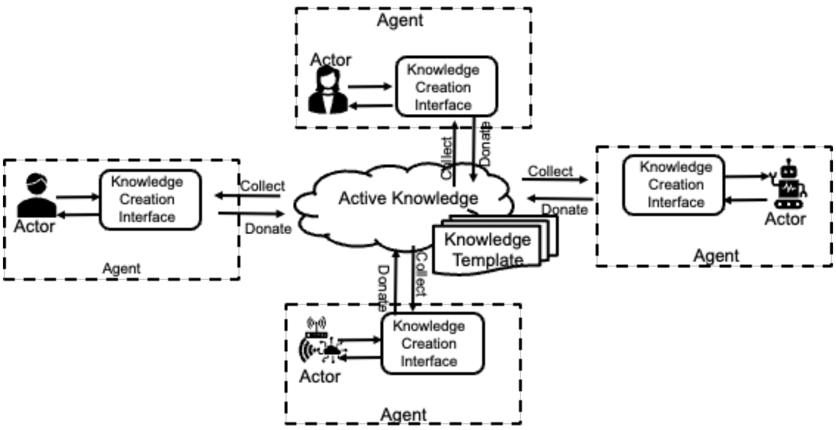


Figure 3.10 Knowledge-creating activity environment framework

3.5.1. Active Knowledge:

Active knowledge is adaptable information that has the properties of understandable and editable, which is the basis of knowledge experience. It consists of Readings/Result and Method.

1) Readings/Result: Measured value, processing result. Multiple values are collectively treated as a data set according to the purpose and intention of the activity area.
2) Visualize Method: Visualize Readings/Results with a graph.
3) Operation Method: Performs processing such as aggregation and selection for Readings/Results.

These are created based on the knowledge template of knowledge required for the target activity. Knowledge Template is a model that expresses the structure of knowledge including the purpose, intention, meaning, and consciousness related to the activities of the Actor.

3.5.2. Knowledge Creation Interface:

Knowledge Creation Interface is an interface for manipulating and visualizing knowledge and generating new knowledge. The interface requirement for knowledge creation is to support the user's understanding of Readings/Result, Visualize Method, and Operation Methods, and to combine them appropriately. And, in those activities, it is supported to acquire findings and discoveries through exploratory and trial-and-error. In this prototype system, the basic operation in the part corresponding to the Knowledge Creation Interface is the Command Line Interface (CLI), and it may not be easy for the curator to operate. However, as a function, it has been confirmed that it can sufficiently support the search and analysis of the viewing experience, so it can be expected that a better support environment will be realized by considering and applying an interface that matches the activities of the curator.

3.5. Conclusion

An environment design based on the concept of knowledge experience was presented. The design was also evaluated by demonstrating possible analysis and interpretation of visitor behavior and the creation of corresponding knowledge-based on the data collected. In this initiative, an environment was designed to create knowledge such as findings and learning. This environment focuses on being understandable and editable and provides the user with knowledge structure and knowledge-handling operations. And knowledge creation examples based on actually collected data show that this design reuses knowledge and encourages knowledge creation.

The concept of knowledge experience is the creative use of knowledge, incorporating the Collect-Explore-Donate of knowledge into the targeted activity. The target of Collect-Explore-Donate includes not only information as a result of activities (so-called declarative knowledge) but also procedures including logic and algorithms (so-called procedural knowledge). Furthermore, it is necessary to design the structure of knowledge related to the target activity as a Knowledge Template and maintain the properties of being understandable and editable to adapt for activities. This is the result of a knowledge-centered approach, which is a unique perspective of this framework. The framework derived this time is a design-level reference to realize them. This reference is useful for designing systems that actively promote knowledge creation through trial and error, such as effective data exploration and discovery of combination patterns.

The design method will be presented based on this reference in the next chapter.

Chapter 4

Design method of Knowledge Driven Human-Computer co-Creation Environment

This chapter introduces a new concept of knowledge experience and proposes it as a design method to design a knowledge-driven collaborative creation environment between humans and computers. This method promotes knowledge creation by focusing on individual activities (user experience). It also encourages sharing knowledge gained from individual activities to improve the quality of other activities.

4.1. Knowledge Experience

Knowledge experience is a new concept that includes: 1) Incorporating knowledge creation, sharing, and utilization into the process; 2) Using knowledge to improve the quality of activities in line with purpose and intent; 3) Record the findings and learning gained from the activity as shared knowledge for use in other activities. This will improve the quality of the activity periodically and sustainably. By defining activity as a knowledge-creating process and providing the knowledge to support the execution of each step that makes up the activity, the activity can become a knowledge experience. Knowledge Experience Design (KED) method was applied as the basis for collaborative design focusing on user experience. Knowledge Experience is a cyclical mechanism that expresses and shares the user experience, which is an individual activity, in a reusable format and shares it to improve the quality of the user experience of another individual (Figure 4.1).

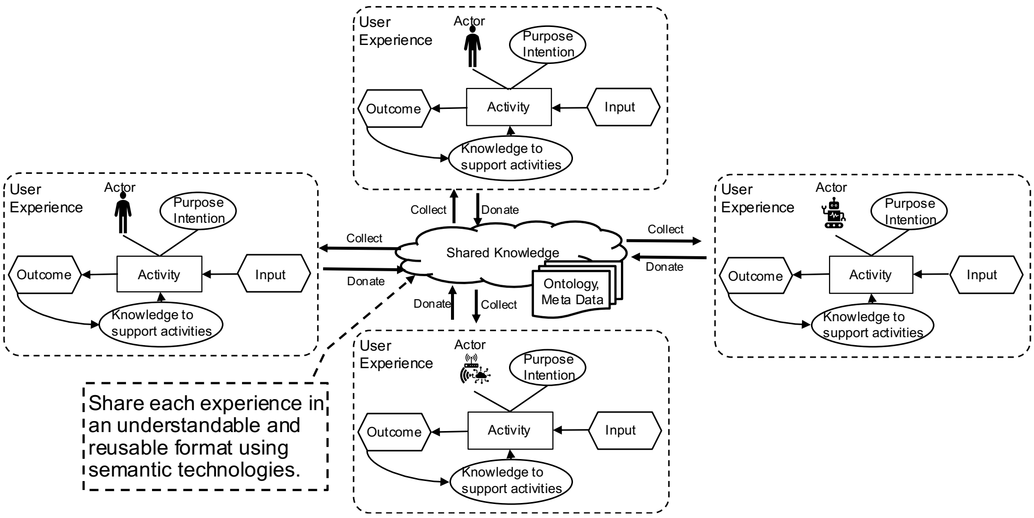


Figure 4.1 Overview of Knowledge Experience

In the Knowledge Experience, the Actor collects the activities of other related Actors to improve the quality of each activity and donates each experience as knowledge to support the activities of other related actors. To use and share it as knowledge, it is necessary to record it in a format that each actor can understand and utilize. In the Knowledge Experience, the semantic intelligence technologies, Ontology and Meta Data, are designed and applied to close each gap and enable mutual understanding and utilization.

4.2. Design steps

Activities designed as knowledge experiences consist of a knowledge creation process and knowledge that activates the activity (after this, referred to as Active Knowledge). KED is a method for incorporating the knowledge creation process and active knowledge into the target activity. The following steps configure KED.

4.2.1. Clarification of the target activity

Extract the input and result (as "Input", "Outcome") of the activity, actor (as "Actor"), activity (as "Activity"), purpose/intention (as "Purpose/Intention") of the activity (in other word "Object extraction"). Designing based on the concept of Knowledge Experience consists of two substeps. In substep 1, the target of systemization is modeled by focusing on input and outcome (deliverables and information) of Actor and Activity (Figure 4.2).

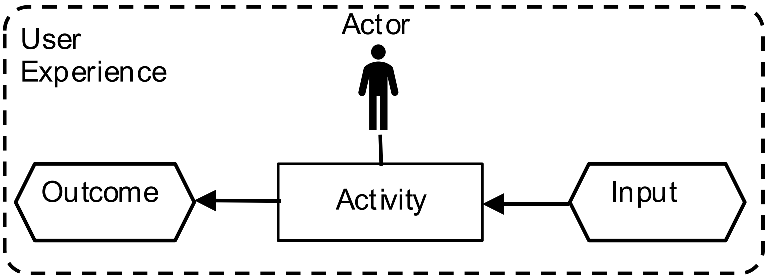


Figure 4.2 substep 1: Focus on Actor, Activity, input, and outcome

Substep 2 adds the following elements to the model in Step 1 (Figure 4.3): (1) Purpose and intent of the activity; (2) Data that supports the activity; (3) Source of data that supports the activity (User Experience itself).

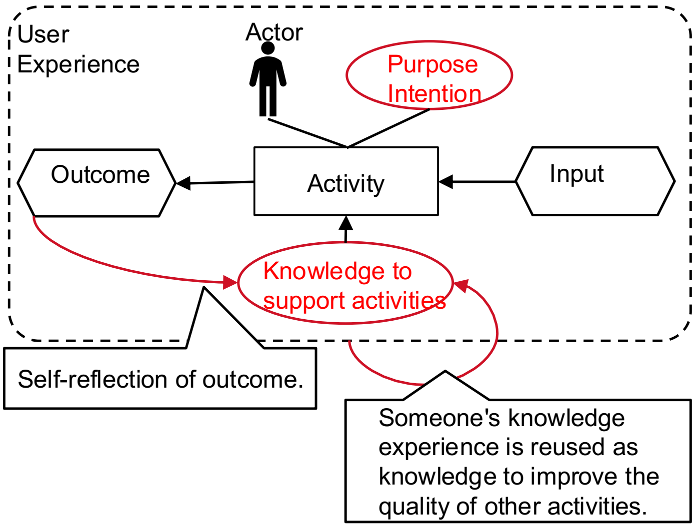


Figure 4.3 substep 2: Add some elements related to the activity

In an environment based on the concept of Knowledge Experience, knowledge is cyclically and sustainably generated, utilized, and executed as a real activity. In the creation and use of knowledge, it is always a challenge that there is not a small amount of knowledge that cannot be used even if it is shared, and it is known as Inert Knowledge [7]. In response to this, an approach that promotes the use and application of knowledge by sharing "when," "how," and "why" is being practiced in the field of education [8]. In other words, it will be possible to understand and apply the user experience by providing information on the content of the activity and the input and output of the activity, including the purpose and intention of the activity. Specifically, by utilizing the user experience of others as information to support one's own activities, it can be expected that the experience of others will be shared with the group as knowledge and the quality of the group's activities will be improved cyclically and continuously.

4.2.2. Process restructuring

Restructure activities based on the knowledge creation process (Process design). The knowledge experience defines the knowledge creation process as follows:

1) Collect: Access information to get noticed.
2) Explore: Organize findings as related knowledge (information that enhances the quality of activities).
3) Create: Configure knowledge (information that enhances the quality of activities) as a viable procedure (Work / Step).
4) Execute: Adapt knowledge to an activity.
5) Donate: Share knowledge for reference and application in other activities.

4.2.3. Knowledge design

Design the input and results of activities and the knowledge that supports the activities as active knowledge (Data design). Information is designed to have two properties, 1) Understandable and 2) Editable, to adapt knowledge for an activity. The input and result are not only the resulting value but also the purpose/intention of the information, and the basis/reason (generation method, constraint, basis) of the value are held in association with each other. Active Knowledge makes it possible to understand the information, make changes for contextual application, and use it as useful information to carry out activities.

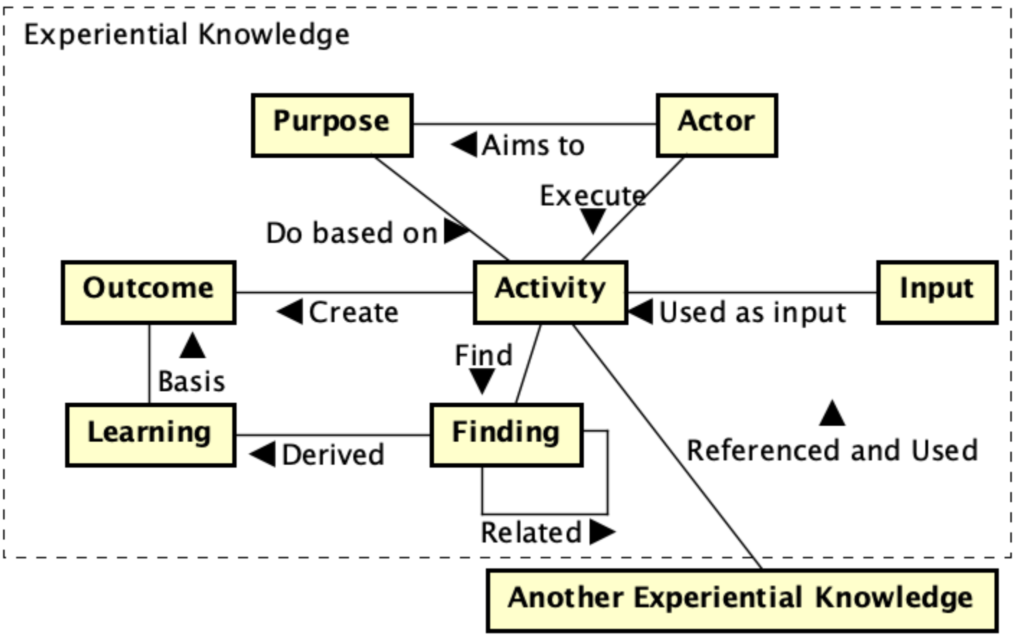


Figure 4.4 Structure of Knowledge

Activities designed as a knowledge experience create experiential knowledge of the structure shown in Figure 4.4. In Figure 4.4, the following things are mentioned in the activity of creating deliverables from input based on purpose: 1) Get noticed from the activity; 2) Derive learning that leads to improvement of the quality of the activity; 3) Utilize in the activity. As an environment that supports such knowledge creation, KED derives the interaction shown in Figure 4.5.

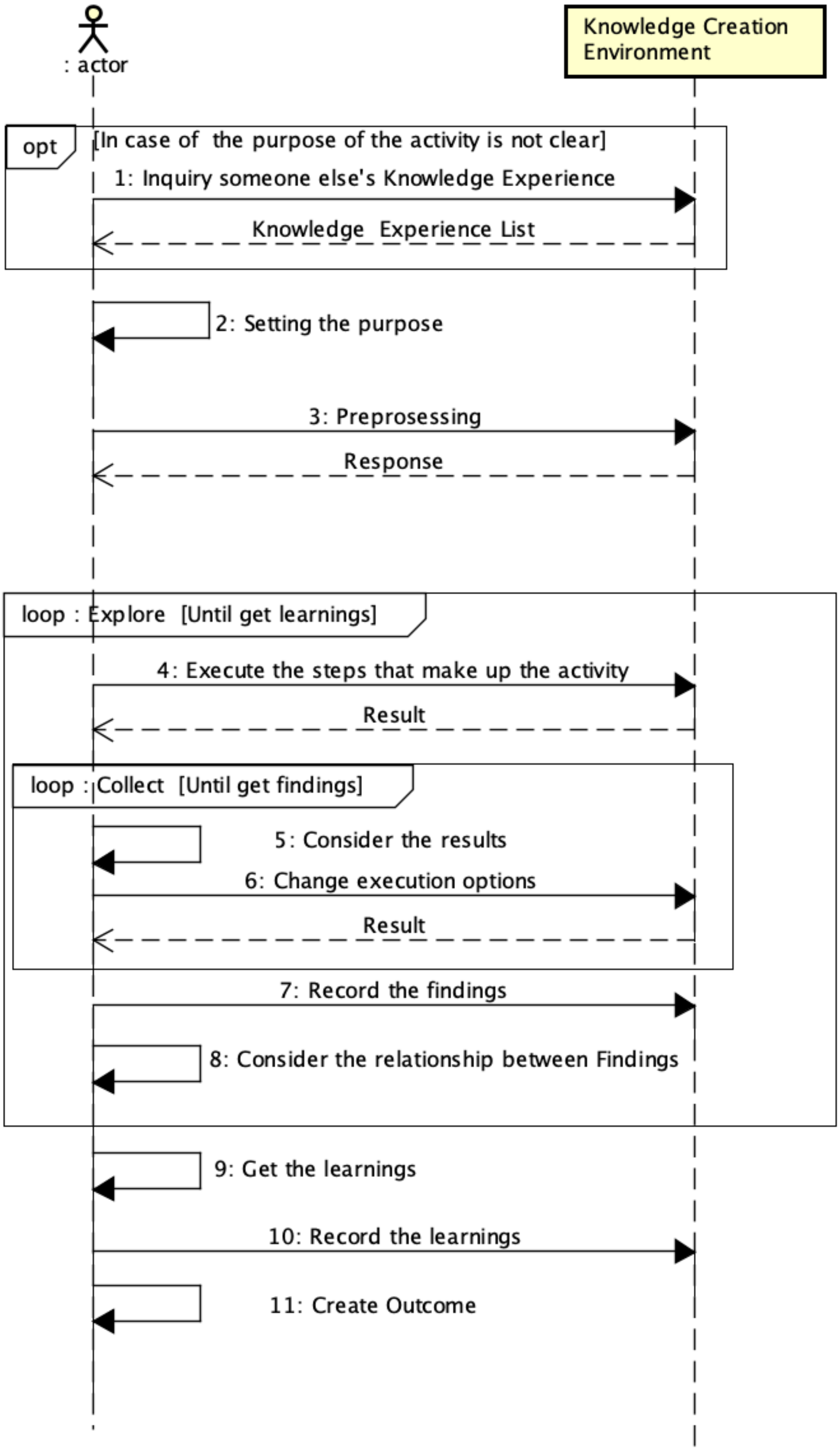


Figure 4.5 Interaction that promotes knowledge creation

The following chapters will show the effect of applying KED to the Smart Museum. First, it is confirmed that KED designs and implements an environment that realizes knowledge creation. Next, it is shown that the knowledge-based activity design based on the analysis of activities by KED has the effect of realizing cooperation among multiple activities and improving the quality of activities.

Chapter 5

Knowledge Creation of Curators at the Smart Museum

This chapter presents a knowledge creation environment's design, implementation, and evaluation results based on the knowledge experience design method. A software system was designed to improve the quality of curator's activities by utilizing information as knowledge, centering on the activities of museum curators, and was evaluated as a design method. It was confirmed that software systems based on knowledge experience enhance the quality of curator activities.

5.1. Introduction

As computers increasingly control and automate important activities and decisions in our lives, there is a growing need to reaffirm the role of humans and design appropriate human-computer collaboration [1]. However, despite such demands, a significant problem in human-computer collaboration is that it is difficult for humans to obtain enough information to understand and use the output of computers [2,3].

Communicating knowledge as instructions and procedures (procedures, rules, and norms) is not enough to enable knowledge to guide decisions and actions. It is necessary to relate and share the basis of knowledge (grounds, reasons, purposes, and intentions) [71]. This discussion is also related to the transparency and explanatory discussion [2,3] of computer calculation results (results of automated learning). Miller's sociological insight into AI's accountability [3] shows that goals or intent usually explain the actions taken. In short, this shows that it is necessary to explain the calculation result and the purpose and intention. Before that, the same thing was said in education [8]. For the recipient of knowledge to understand and use it, appropriate information and explanation are required, and it is necessary to realize it.

As Benbya et al. [15] explain, there is no unified standard knowledge model in various knowledge efforts. Instead, knowledge is integrated by integrating models presented in fields such as knowledge management and learning theory, such as models [15], SECI models [60], and Experiential Learning Theory [70], which are organized based on many Knowledge Management documents. Through the phases of (1) individual learning, (2) learning as an organization, and (3) sharing, it will be shared and widely used by groups and organizations.

In this way, the conventional approach is to externalize, organize, and formalize the knowledge acquired by individuals as an organization. However, it has been pointed out that knowledge acquisition and knowledge extraction are both expensive methods and methods that do not provide sufficient quality [47], which is a significant issue when considering the sharing and use of knowledge in an organization. This chapter will show the design and effect of a knowledge creation platform for human beings to use knowledge in their activities and evolve, deepen, continue, and maintain their activities.

5.2. Related Work

Activities that utilize knowledge to improve the quality of activities include a process called OODA (Observe-Orient-Decide-Action) [85]. Activities based on this process observe the situation based on the data, orient the response, determine the response, and execute it. At this time, skill, rules, knowledge, and experience are required to make decisions according to the situation, and the issue is how to accumulate and make them available.

In manufacturing and engineering, efforts are being made continuously to utilize the knowledge gained from experience for automation. By making decisions such as choices and decisions made by experts into knowledge as data, rules, and procedures, anyone can automatically execute them, and it can be expected to improve activity efficiency. However, automation poses the challenges of black-boxing operations [72] and makes it difficult to understand and pass on knowledge, as pointed out in discussions on the explanation of AI [2, 3]. Therefore, to ensure reliability, safety, and trustworthiness [1] in the collaboration between computers and humans, balancing automation and human control is necessary.

In addition, black-boxing makes it difficult to change rules and standards depending on the situation, making it impossible to respond appropriately to the situation. It is required to share and use knowledge not for automation but for creating new knowledge (learning and awareness of the activity entity itself). Therefore, there is a need to shift to sharing and using knowledge to create new knowledge (learning and awareness of the actors themselves) rather than knowledge for automation. In other words, computers and humans should mutually understand and utilize the results of their activities. And while maintaining an appropriate balance between automation and human control, they carry out activities according to the situation and create new knowledge (awareness and discoveries). This work will show such a series of activities based on knowledge is called Knowledge Experience and propose an environment design method that enables anyone to experience knowledge.

5.3. Modeling Curator Activities with Knowledge Experience Design

The Smart Museum project is a project to improve museum services through information and communication technology and aims to create knowledge through collaboration between humans and computers and provide a viewing experience that suits visitors. One of the activities related to improving museum services is the activity by curators. In the project, the activities of curators are regarded as knowledge experiences, knowledge experience design (KED) is applied, and the environment of software (after this referred to as Curator Agent) that supports the activities of curators is designed and constructed. Furthermore, evaluate the effectiveness of KED by ensuring that the Curator Agent facilitates knowledge creation for curators.

5.3.1. KED of curator activities

The curator's knowledge creation activities include: 1) Get findings from the visitor's viewing experience to improve the exhibition service (provide a high-quality viewing experience to the visitor); 2) Exhibition Derive ideas that lead to improved services; 3) Use ideas to improve exhibition services; 4) Express and share shared knowledge that is useful for the activities of other curators.

By organizing the curator activities based on the steps of KED, the scope of support for knowledge creation by the Curator Agent and the interaction with the curator are designed.

1) Step 1: Clarification of (target) curator activities

First, identify each component of the curator's activities and clarify the activities.

a) Actor: Curator
b) Action: Creating ideas for improving exhibition services

   The curator grasps the appreciation behavior of the visitors and creates improvement ideas as knowledge along with the grounds. The execution of knowledge (= execution of ideas to improve) involves actual activities in the real space (museum). To configure an improvement idea as a feasible procedure (Work/Step), information on activities in real space (exhibits, exhibition design contents, etc.) is required. So, the scope of support of Curator Agent is limited to the creation of improvement ideas.
c) Purpose and intention of the activity: To provide visitors with a high-quality viewing experience.
d) Activity input: Visitor behavior information
   - Purpose/Intention: Quantitatively capture the viewing experience of visitors
   - What to measure: Externally measurable behavior of visitors
   - How to measure: Place a sensor device (after this, referred to as Sensor Agent) in the exhibition hall and use the value measured by Sensor Agent.
e) The outcome of activities: Improving the viewing experience of visitors (increasing the number

of visitors, increasing viewing time) , ideas that lead to improved exhibition services

2) Step 2: Define a knowledge creation process for activities (creating ideas for improving exhibition services)

In step 2, the activity is designed along with the knowledge creation process.

a) Collect: Curators access information for findings. The source of findings is the behavior measurement information of visitors. The curator gives an overview of the visitor's behavior measurement information, selects and visualizes the information of interest, and describes and records the findings.
b) Explore: The curator associates findings and organizes it as learning (information that enhances the quality of the activity). The curator then correlates the recorded findings and, based on that, creates ideas for improving the exhibition, and describes and records it using the Curator Agent.
c) Create: The curator organizes the recorded improvement ideas as actionable steps (Work / Step).
d) Execute: The curator applies knowledge to the activity. Execution of exhibition improvement ideas is carried out as real space (activities outside the Curator Agent).
e) Donate: The entire knowledge experience must be expressed and recorded in a format that the curator can understand to be referenced and applied in other activities. The Curator Agent automatically performs this expression and recording.

4) Step 3: Design the input and results of the activity and the knowledge that supports the activity as Active Knowledge.

As shown in Figure 5.1 the contents organized up to step 2 can be modeled as knowledge.

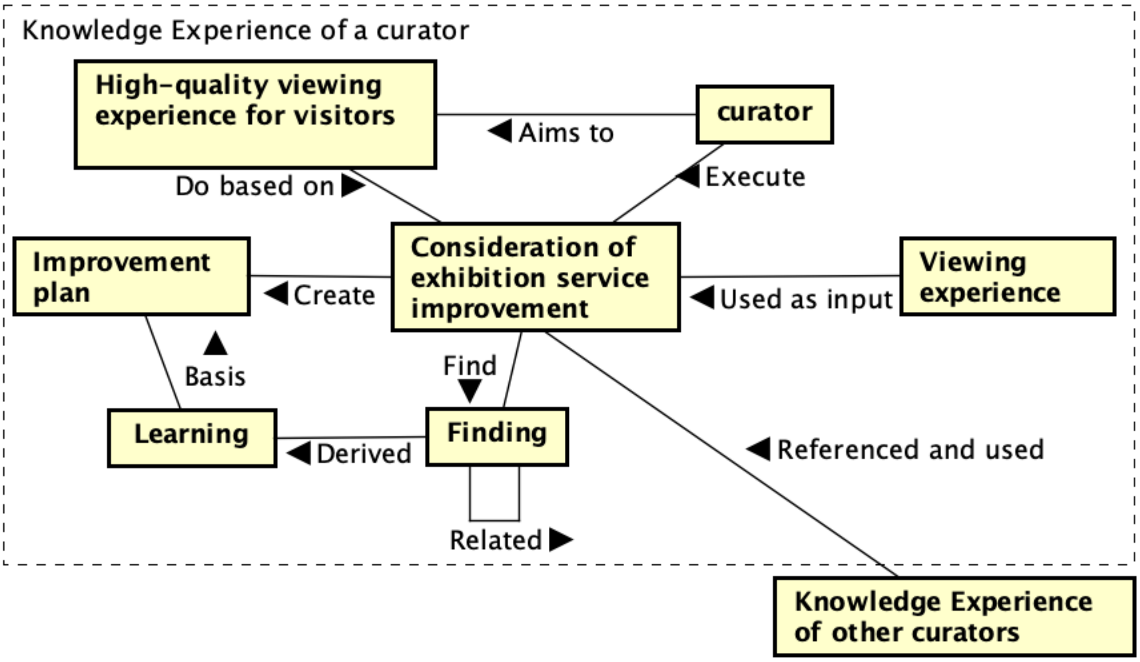


Figure 5.1 Structure of Curator's Knowledge Experience

Furthermore, the interaction between the curator and the Curator Agent to obtain this knowledge experience is designed as shown in Figure 5.2.

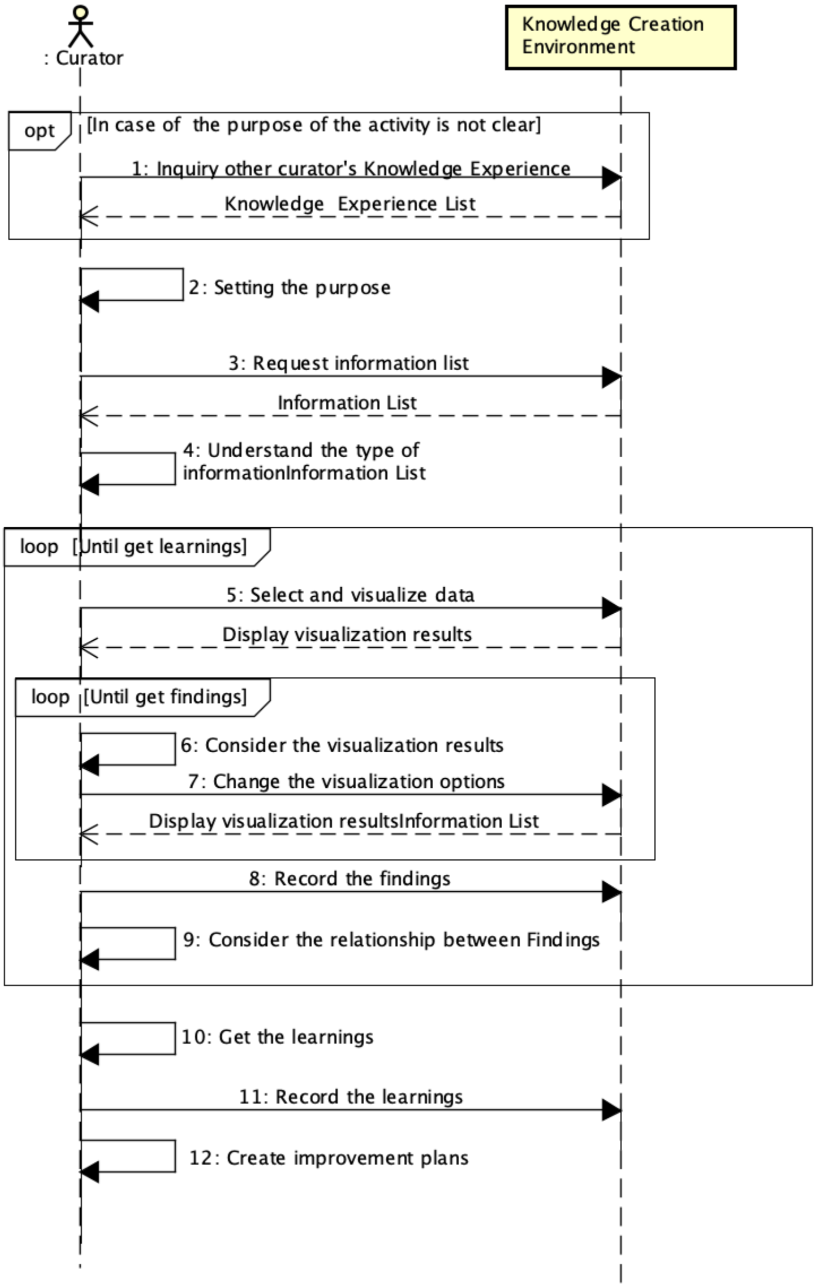


Figure 5.2 Interaction of Curator's Knowledge Experience

5.3.2. Implementation of Curator Agent

The designed interaction between the curator and the Curator Agent is applied to actual activities, and the curator's ability to promote knowledge creation is evaluated. The Curator Agent prototype system (CA prototype) was implemented based on the KED of curator activities. The prototype system verifies that the curator-Curator Agent interaction, designed based on Knowledge Experience, facilitates the curator's knowledge creation. Furthermore, the purpose is to extract issues when regularly operating as a knowledge creation environment.

1) Features of CA prototype

The CA prototype provides an environment for curators to visualize and observe the data themselves to understand visitors' viewing experience and create knowledge that can be shared with other curators. Specifically, it achieves the following:

a) By expressing and recording findings for the visualized results, it is promoted to observe the data fully.

b) Compare, correlate, and organize the findings with the underlying data and visualization results, consider what was happening in the exhibition hall, and express and record it as learning At this time, it is possible to refer not only to the findings recorded by oneself but also to the findings recorded by others, along with the data and visualization results that are the basis for this. As a result, it is expected that findings from a different perspective will be acquired, and learning will be gained from various perspectives.

c) By separating learning and the creation of service improvement ideas as a process, it is possible to create ideas by comparing multiple learning and also to create various ideas from one learning

These methods apply the appreciation support method based on the interactive appreciation method such as VTS (Visual Thinking Strategies) [83], which was also used in the research related to Active Knowledge (knowledge-based research on the appreciation experience of artworks) [84,85,86].

2) Overview of CA prototype

The CA prototype implements the interaction model that supports the knowledge creation activities of the curators introduced earlier and constructed the knowledge model. Figure 5.3 shows the basic screen configuration of the CA prototype. The users of this Curator Agent (hereinafter referred to as the operators) can see that the page structure corresponds to each step of the interaction.

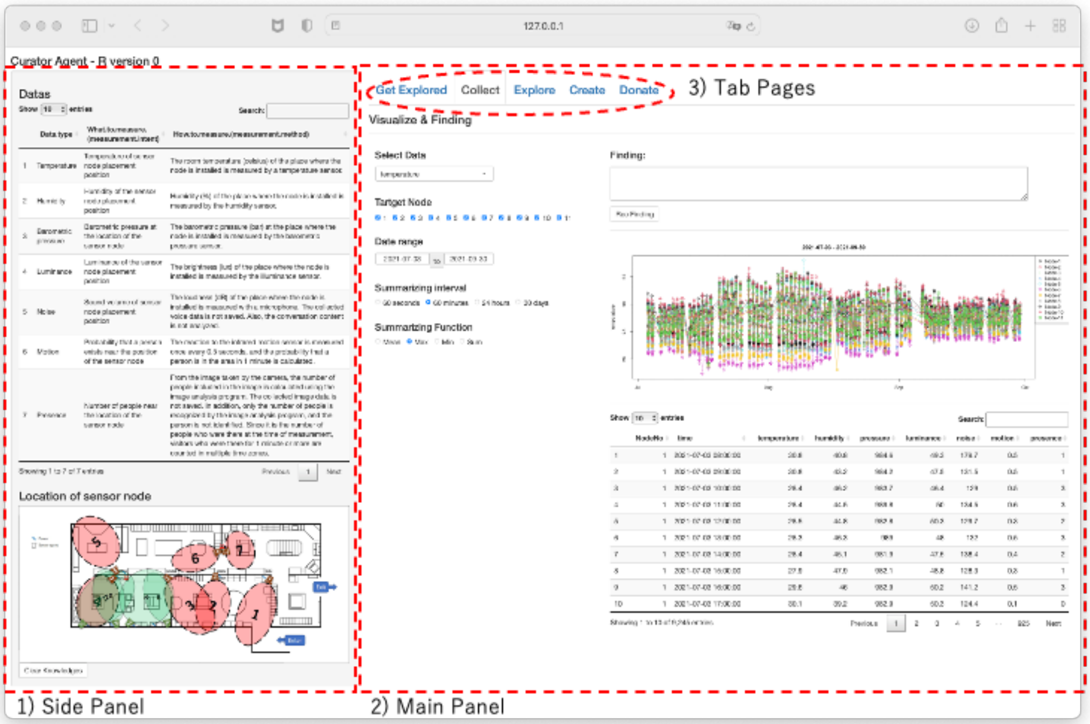


Figure 5.3 Overview of CA prototype

a) Side Panel

The side panel always displays information about the data items available in the Curator Agent. The operators can check information about data items at any time while operating the main panel.

b) Main Panel

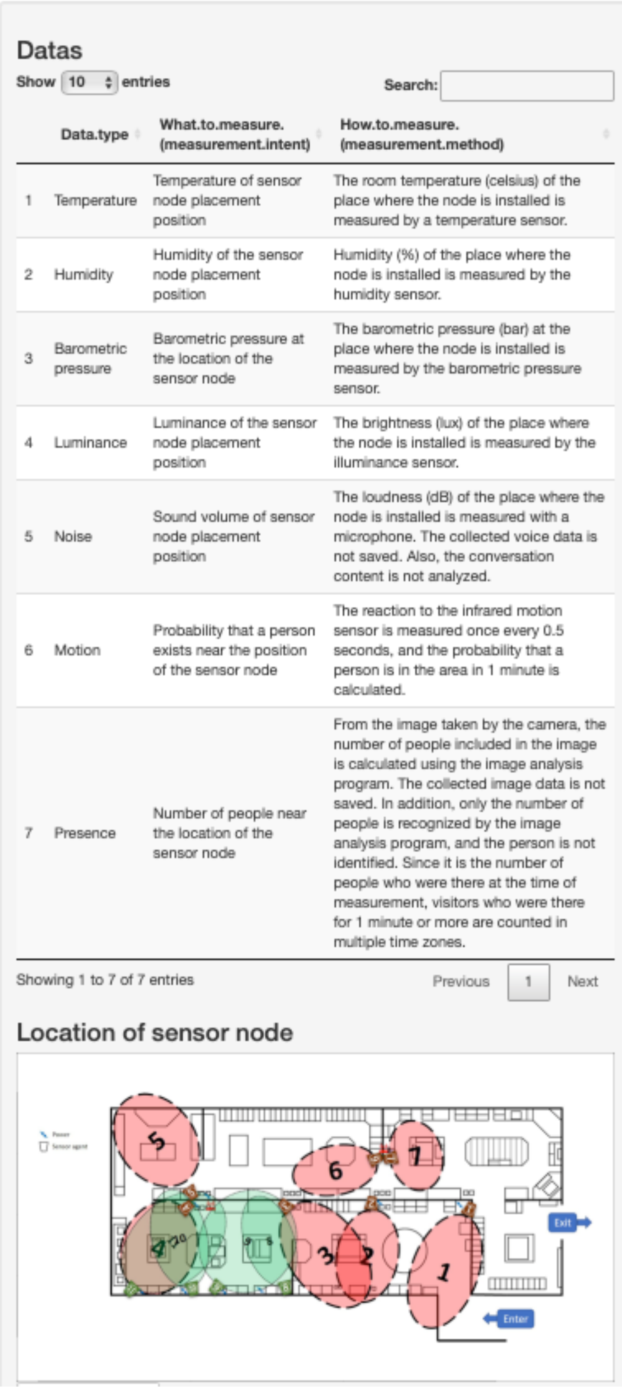
The main panel has features for an exploratory understanding of the visitor's viewing experience, deriving ideas, and forming shared knowledge that is useful for the activities of other curators. The main panel consists of tab pages corresponding to the knowledge creation process and supports the operators to carry out activities according to the knowledge creation process.

c) Tab Pages

It consists of a page corresponding to the knowledge creation process (Collect, Explore, Create, Donate) and a page introducing how to use the Curator Agent ("Get Explored").

3) CA prototype: Side Panel

The side panel (Figure 5.4) always displays information about the data items available in the Curator Agent. The data description provides the type (name) of the data item and the measurement intent and measurement method of the measurer (Sensor Agent in this example). By interpreting the meaning of the data from the measurement intention and the measurement method, the operator observes the data, gains findings and learning and guides the operator to understand it. If judging only by work efficiency, it is necessary to prioritize discovering the problems of the exhibition service with less effort. However, considering the operator's growth, it is necessary to acquire findings and learning The idea of Knowledge Experience is to place importance on it.



Datas

Show 10 entries Search:

	Data.type	What.to.measure. (measurement.intent)	How.to.measure. (measurement.method)
1	Temperature	Temperature of sensor node placement position	The room temperature (celsius) of the place where the node is installed is measured by a temperature sensor.
2	Humidity	Humidity of the sensor node placement position	Humidity (%) of the place where the node is installed is measured by the humidity sensor.
3	Barometric pressure	Barometric pressure at the location of the sensor node	The barometric pressure (bar) at the place where the node is installed is measured by the barometric pressure sensor.
4	Luminance	Luminance of the sensor node placement position	The brightness (lux) of the place where the node is installed is measured by the illuminance sensor.
5	Noise	Sound volume of sensor node placement position	The loudness (dB) of the place where the node is installed is measured with a microphone. The collected voice data is not saved. Also, the conversation content is not analyzed.
6	Motion	Probability that a person exists near the position of the sensor node	The reaction to the infrared motion sensor is measured once every 0.5 seconds, and the probability that a person is in the area in 1 minute is calculated.
7	Presence	Number of people near the location of the sensor node	From the image taken by the camera, the number of people included in the image is calculated using the image analysis program. The collected image data is not saved. In addition, only the number of people is recognized by the image analysis program, and the person is not identified. Since it is the number of people who were there at the time of measurement, visitors who were there for 1 minute or more are counted in multiple time zones.

Showing 1 to 7 of 7 entries Previous 1 Next

Location of sensor node

Figure 5.4 CA prototype: Side Panel

4) CA prototype: Get Explored tab page

Figure 5.5 CA prototype: Get Explored tab page

The Get Explored tab page (Figure 5.5) provides a guide on the basics of using the CA prototype, and scenario examples to help explore the viewing experience of visitors. The information provided on this page will help initiate an exploratory understanding of the visitor's viewing experience without the premise of knowledge or experience with the procedure.

5) Tab Page: Collect

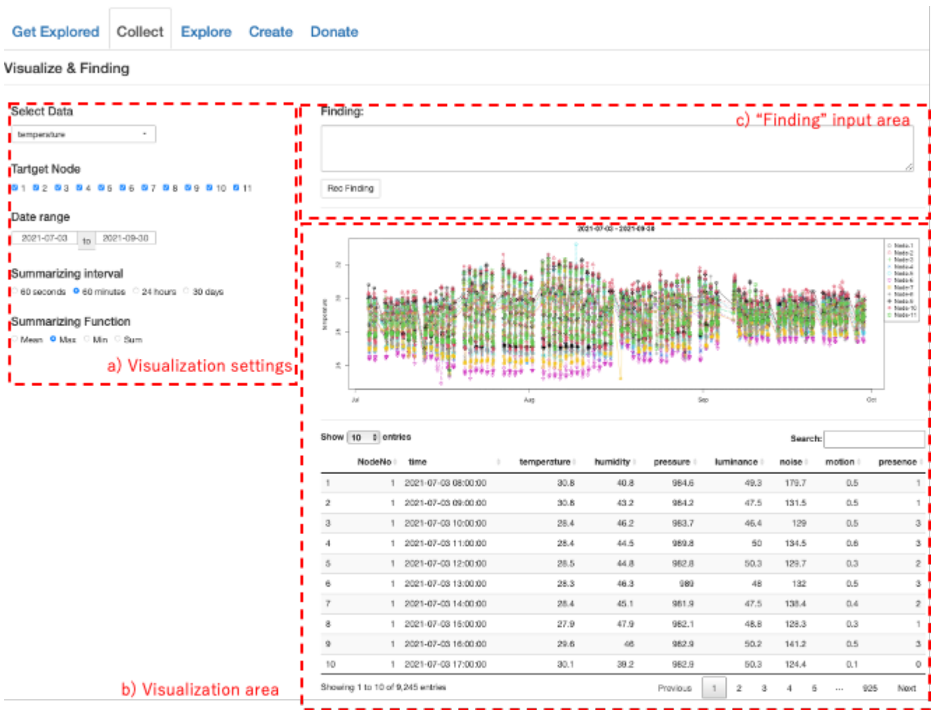


Figure 5.6 CA prototype: Collect tab page

On the Collect tab page (Figure 5.6), the operators can visualize the data and enter findings about the visualized data. In the visualization setting (a), select the data to be visualized. Furthermore, the target sensor node, the period of data, the unit for aggregating data (1 minute, 1 hour, one day, 30 days), and the operation used for aggregation (mean value, maximum value, minimum value, total value) can be specified. The data is displayed in visualization area (b) in graph and tabular format according to the settings. Finally, the operators observes the visualized data, expresses findings and inputs it (c).

6) Tab Page: Explore

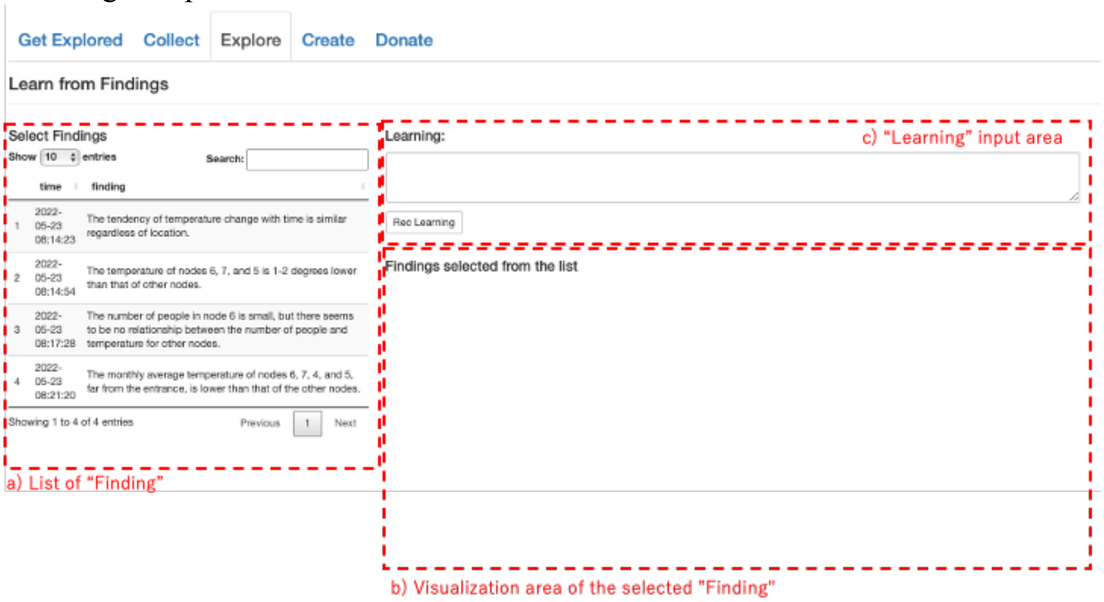


Figure 5.7 CA prototype: Explore tab page

The Explore tab page (Figure 5.7) displays a list of previously recorded findings. The list shows not only what the operator oneself recorded but also findings recorded by others. This makes it possible to know findings other than oneself and consider learning from various perspectives. The operator can check the contents in the visualization area (b) by selecting findings from the list (a). The operator then observes the visualized findings, considers and expresses learning and inputs it (c).

7) Tab Page: Create

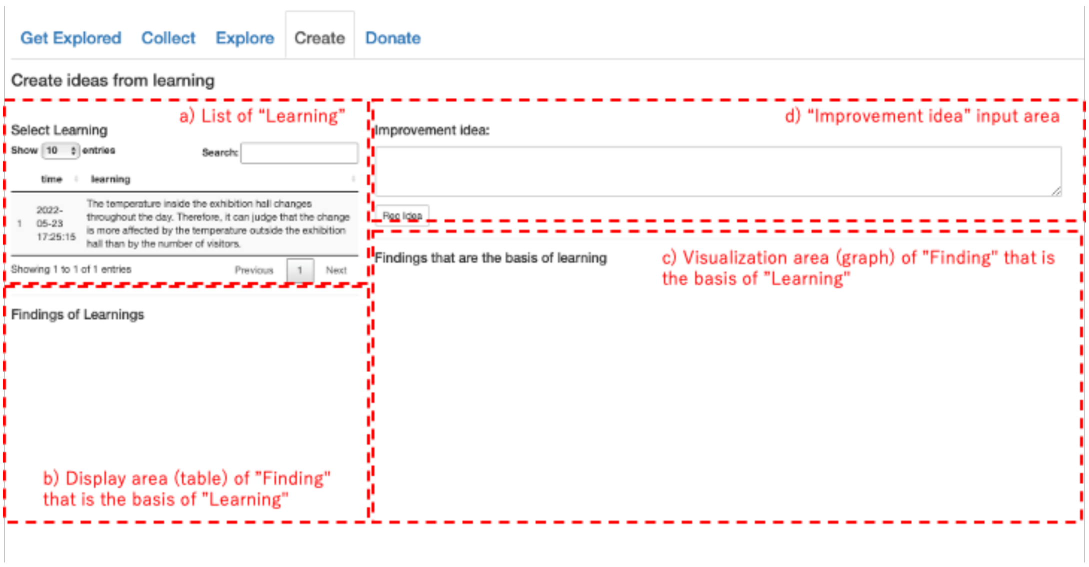


Figure 5.8 CA prototype: Create tab page

The Create tab page (Figure 5.8) shows a list of learning that has been recorded so far. The list includes learning recorded by the operator oneself and the learning recorded by others. This allows an operator to know learning other than oneself and think about ideas from various perspectives. By selecting learning from the list (a), the findings that is the basis of learning is displayed in the visualization area (table format: a, graph format: c). And the operator derives improvement ideas from findings and learning expresses them, and enters them (d).

8) Tab Page: Donate

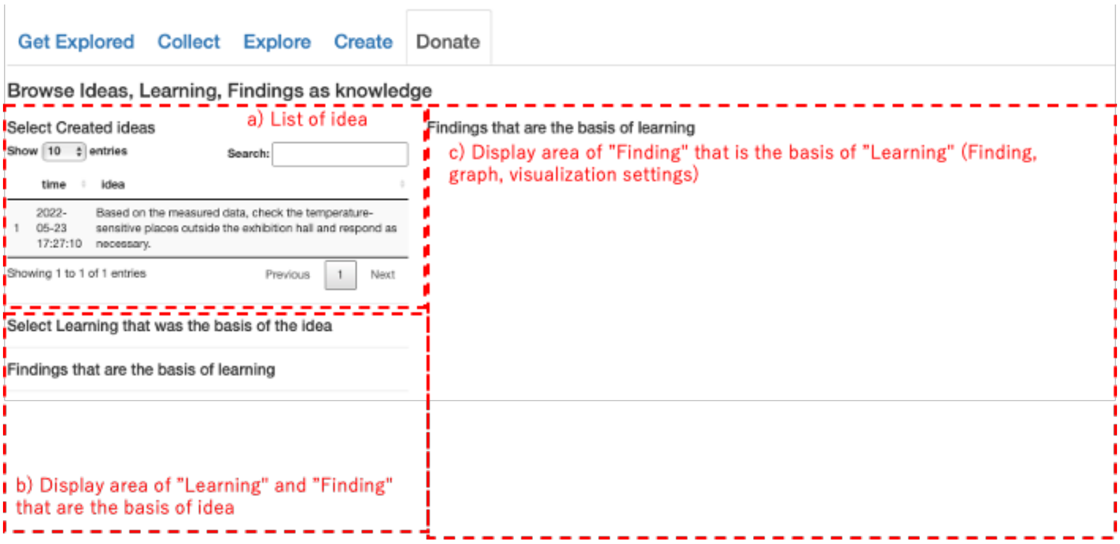


Figure 5.9 CA prototype: Donate tab page

The Donate tab page (Figure 5.9) shows a list of previously recorded ideas. The operator can refer to the created knowledge by selecting an idea from the list (a). In the display area, the learning and findings that are the basis of the chosen idea are displayed in area (b). In addition, detailed information about findings (contents of findings, underlying graphs, data visualization settings) is displayed in area (c).

5.4. Evaluation of Knowledge Creation through Interaction between Curator and Curator Agent

The designed interaction between the curator and the Curator Agent is applied to actual activities, and the curator's ability to promote knowledge creation is evaluated. The activity scenario to be covered is to check the room temperature of the exhibition hall, learn how to maintain an appropriate viewing environment, and create a plan that will lead to the improvement of the exhibition service. In this scenario, it is assumed that the curator has a clear understanding of the purpose of the activity. If unclear, the curator can set the purpose of the activity by referring to and using the knowledge experience of other curators created in the same way. This scenario is performed as an interaction between the curator and the Curator Agent as follows. In the scenario presented below, the data measured between July 3, 2021, and October 2, 2022, is used as an example.

5.4.1. Request information list:

The curator refers to the data list to see what data is available. The curator gets a list of the data shown in Side Panel to understand what is being measured and how is it being measured for temperature. The temperature data is the value measured by the temperature sensor at the room temperature (Celsius) of the place where the sensor is installed.

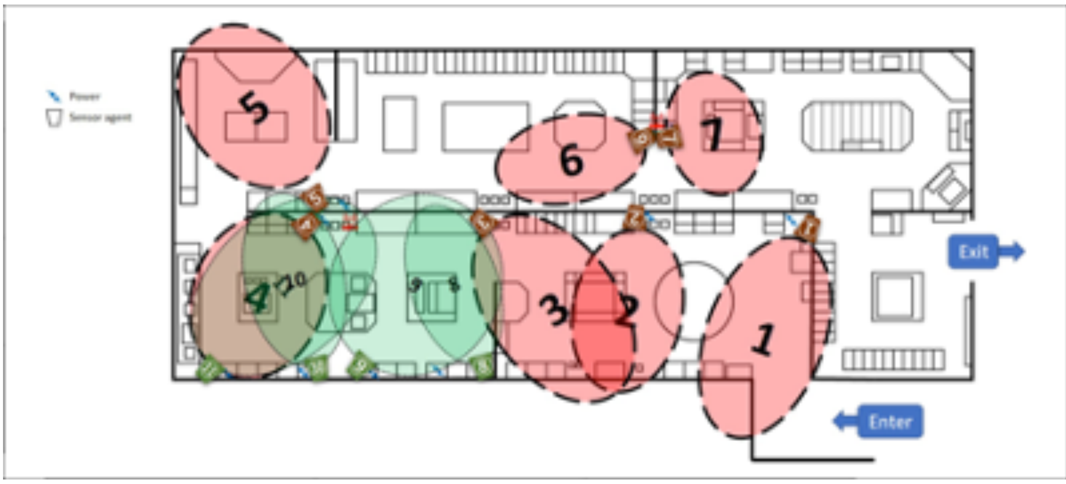


Figure 5.10 Location of sensor node

Furthermore, the curator has a question about where the sensor is installed. Therefore, by referring to the sensor layout (Figure 5.10), the curator understands that the sensors are installed in 11 places in the exhibition hall.

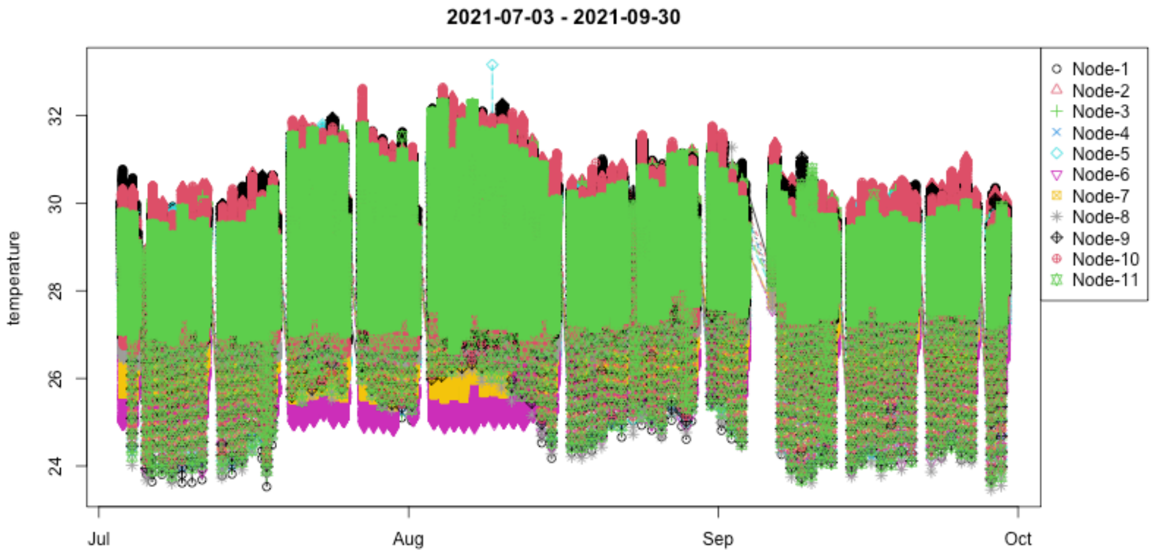


Figure 5.11 Graph1: Exhibition Hall Temperature (first visualization)

5.4.2. Select and visualize data

Next, select temperature data and graph it to check, “Is the room temperature in the exhibition hall constant where the sensor is installed?” First, graph it as it is (Figure 5.11). If the data measured every minute is graphed as it is, the lines and points in the graph are too fine to understand the tendency. Therefore, the curator decides to graph the average temperature for each hour of August (Figure 5.12).

It can be read that the temperature differs depending on the location. The curator can also see that the temperature changes with time. Moreover, the tendency of the temperature to change with time seems to be a similar pattern regardless of the location. The curator records this as Finding1.

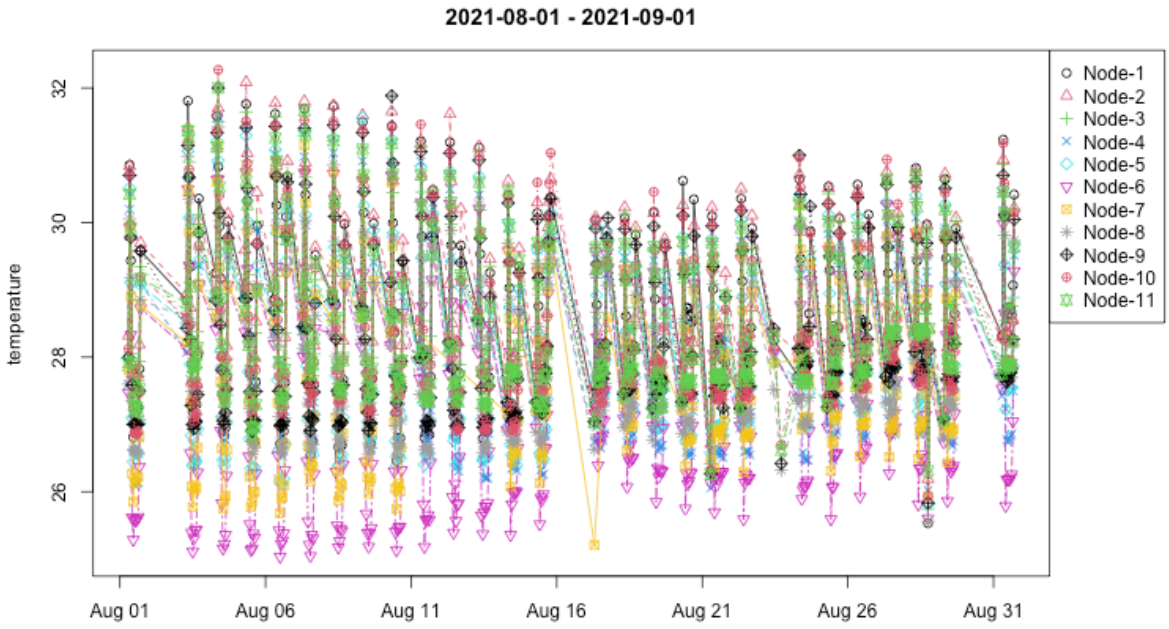


Figure 5.12 Graph2: Exhibition Hall Temperature (August 2021)

	NodeNo	time	temperature	humidity	pressure	luminance	noise	motion	presence
1	1	2021-08-01 07:00:00	28	47.3	977.3	46.4	105.4	0	0
2	1	2021-08-01 08:00:00	30.9	39.8	977.2	47.1	113.5	0	0.1
3	1	2021-08-01 09:00:00	29.4	43.1	977.2	47.2	113.9	0	0
4	1	2021-08-01 10:00:00	27.8	41.7	977.1	46.9	115.5	0.1	0.4
5	1	2021-08-01 11:00:00	26.8	44.8	976.9	46.3	118	0.2	0.9
6	1	2021-08-01 12:00:00	27.1	45.5	976.7	46.2	115.3	0.1	0.4
7	1	2021-08-01 13:00:00	27.2	45.6	976.3	47	114	0.2	0.9
8	1	2021-08-01 14:00:00	27.3	45.5	976.3	48	114.8	0.2	0.8
9	1	2021-08-01 15:00:00	27.3	46.4	976.3	47.6	115.7	0.2	1.2
10	1	2021-08-01 16:00:00	27.8	44.1	976.6	47.8	111.6	0.1	0.3

Figure 5.13 Record of Finding1 on the Collect tab page

On the Collect tab page of the CA prototype, the operator sets the visualization, displays the graph, and observes it (Figure 5.13). Then, the operator inputs the obtained findings and clicks the record button. Then redisplays the graph, focusing on August 4, which shows the highest temperature (Figure 5.14).

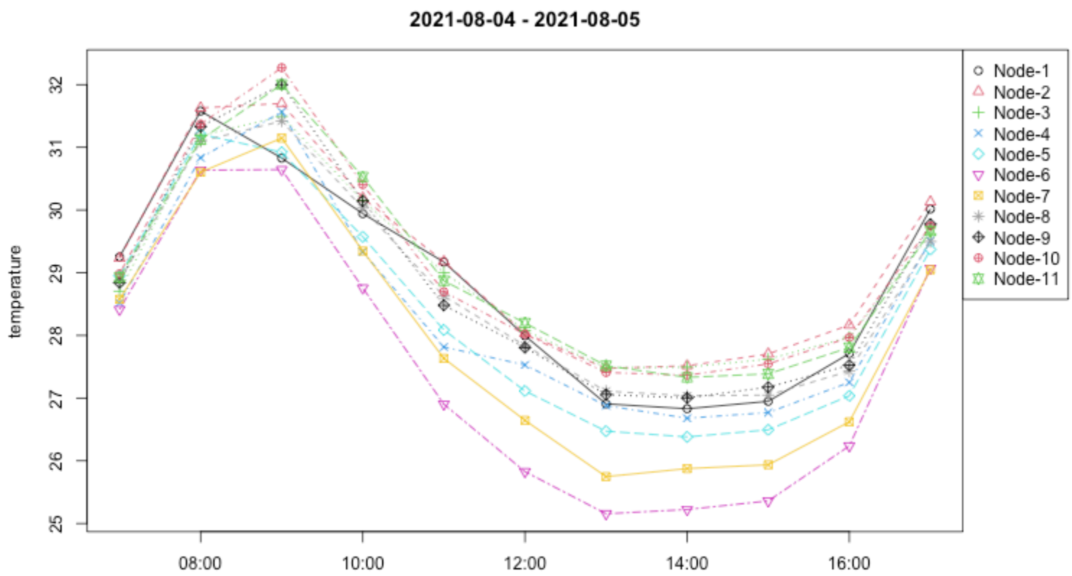


Figure 5.14 Exhibition Hall Temperature (August 4, 2021)

Curators will find that the temperatures at nodes 6, 7, and 5 are 1-2 degrees lower than the others. This is also recorded as Finding2.

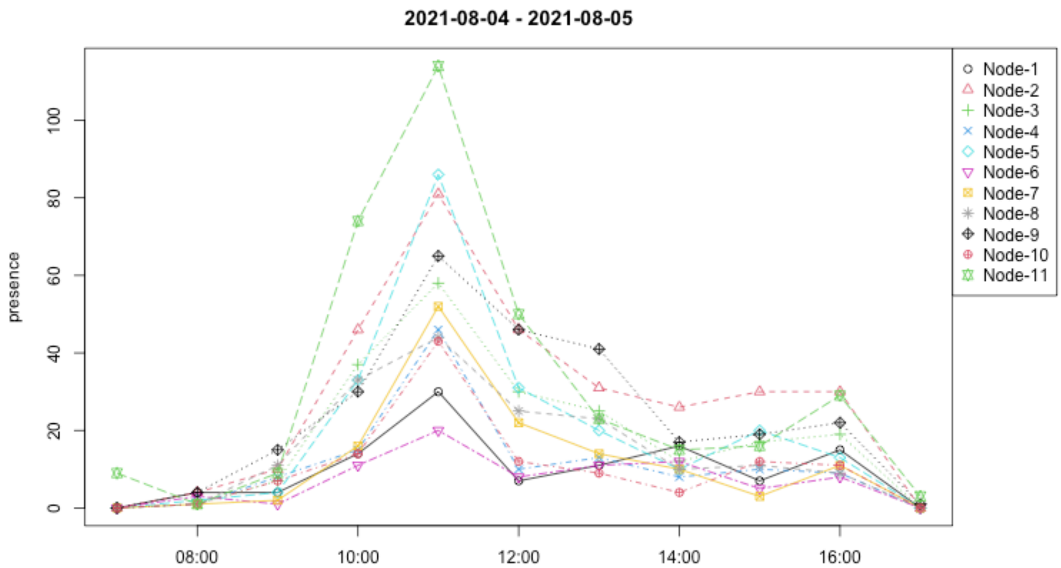


Figure 5.15 Graph4: Number of people (August 4, 2021)

In addition, curators are concerned about whether temperature changes are related to the number of people. Therefore, for the number of people, similarly, graph the average value for each time zone and node on August 4th (Figure 5.15). Certainly, the number of people in node 6 is small, but there is no relationship between the number of people and the temperature for other nodes. This is also recorded as Finding3.

The sensor layout shows nodes 6, 7 and 5 are far from the entrance. It may be because it is far from the entrance and is not affected by the temperature outside the exhibition hall. Therefore, the curator graphs the monthly average value for the temperature data from July to September (Figure 5.16).

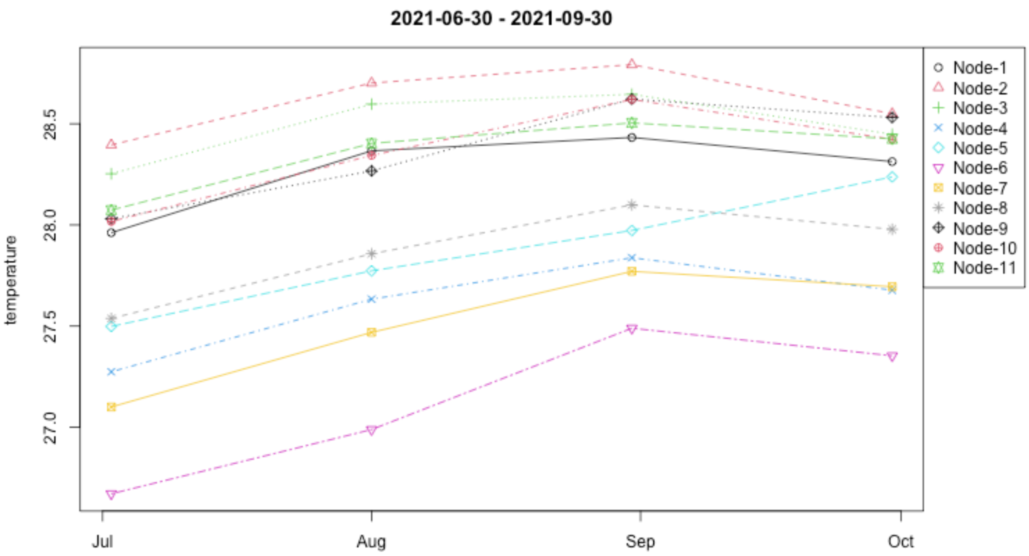


Figure 5.16 Graph5: Exhibition Hall temperature (monthly average from July to September 2021)

The curator understands that even monthly average temperatures are lower for nodes 6, 7, 4, and 5 far from the entrance. Therefore, this is also recorded as Finding4.

5.4.3. Considers the findings: Organize the findings and derive learnings.

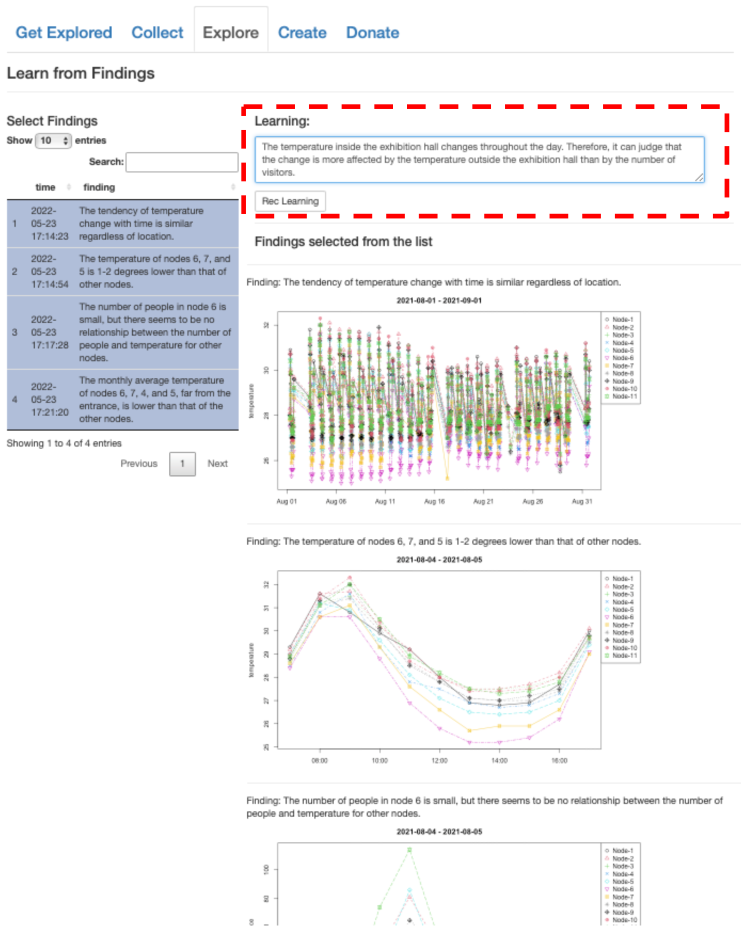


Figure 5.17 Record of Learning on the Explore tab page

By relating and organizing the findings so far, the following learnings can be gained. The temperature inside the exhibition hall changes throughout the day. It is thought that the change is more affected by the temperature outside the exhibition hall than by the number of visitors. Therefore, to keep the viewing environment comfortable, it is desirable to adjust according to the conditions, such as the outside temperature and the location. Record this as Learning.

The operator selects Finding1-4 from the list on the Explore tab page of the CA prototype (Figure 5.17). Each Findings and the graph on which it is based are displayed in the display area. Next, the operator enters (b) what he has observed and considered learning and clicks the record button.

5.4.4. Create a plan: Derives improvement plans from learning

The exhibition environment affects the viewing experience, so it is necessary to maintain an appropriate environment. The room temperature in the exhibition hall is one of them. Since the range of temperature change varies depending on the location inside the exhibition hall, it is necessary to confirm the location outside the exhibition hall that is susceptible to temperature and make necessary adjustments based on the measured data.

The operator selects the appropriate learning from the list on the Create tab page of the CA prototype (Figure 5.18). In the display area, the findings that is the basis of the selected learning is displayed in the format of table (a) and graph (b). The operator observes the contents and considers ideas for improving the exhibition. Then enter the idea (c) and click the record button.

Figure 5.18 Record of idea on the Create tab page

Based on this scenario, interaction between the curator and the Curator Agent creates the graphs, findings, learning, and ideas for improvement as knowledge (Figure 5.19).

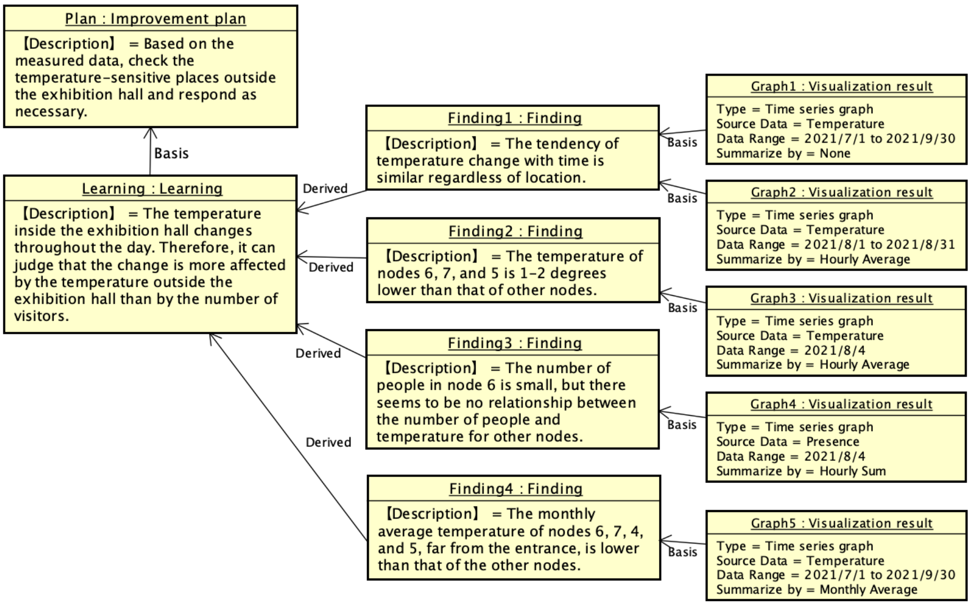


Figure 5.19 Result of Knowledge Creation

5.4.5. Evaluation of knowledge creation interactions based on scenarios

Operators can see the knowledge generated by selecting the desired idea from the list of ideas (a) on the Donate tab page of the CA prototype (Figure 5.20). In the display area, the learning and findings that are the basis of the selected idea are displayed in area (b). In addition, detailed information about findings (contents of findings, underlying graphs, data visualization settings) is displayed in area (c).

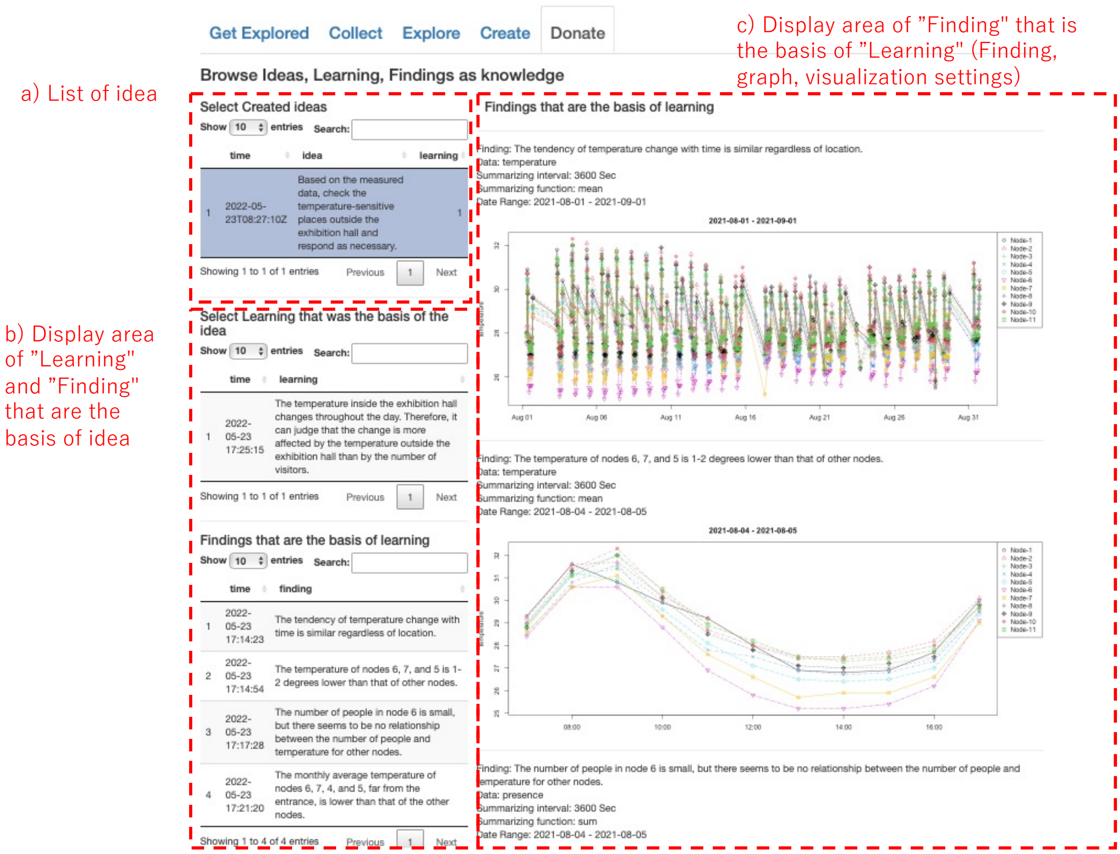


Figure 5.20 Browse Knowledge on Donate tab page

In addition, the knowledge created in this trial is recorded at a level where other curators can relive the same activity (exploratory analysis on temperature) like this time. Also, using this information, a similar search can be performed by replacing the temperature with other data such as humidity. From this, it can be determined that the knowledge created by the knowledge experience is understandable, editable to adapt to activity. In this way, the CA prototype is an implementation that follows the interaction designed by the curator's knowledge creation activities. It was also found that the knowledge (idea-learning-findings) finally obtained by using the CA prototype is in line with the knowledge structure designed by the curator's knowledge creation activities. In addition, the knowledge created in this trial is recorded at a level where other curators can relive the same activity (exploratory analysis on temperature) like this time. In other words, the operators can do a similar search by replacing temperature with other data such as humidity in this information.

From the following points, it can be judged that the knowledge created by the knowledge experience is understandable and editable.

- The rationale is related, and the structure is understandable to others.
- It is possible to create new knowledge (findings, learning, and ideas) by using the recorded visualization settings, learning, and findings as they are. It can be applied and implemented as knowledge in other people and other cases.
- Visualization results and settings, visualization results and learning, learning and findings, findings and ideas can be referenced from any Knowledge Creation step (Collect, Explore, Create). And it is possible to create new knowledge by rearranging those relationships (it has an editable structure).

5.4.6. Evaluation of the interaction of knowledge creation based on the curator's trial of CA prototype

The effect of the interaction between the curator and the curator agent in creating knowledge was evaluated by having a curator try the CA prototype, also. The subjects are five museum curators with good knowledge of the museum's exhibits. The subjects were provided with the same environment (CA prototype, scenario, data) introduced in the previous section. After explaining how to use the CA prototype, the subjects experienced knowledge creation using the CA prototype in about 10 to 15 minutes while referring to the scenario. After that, a questionnaire was conducted on the subjects, and an evaluation was performed based on the response results. The contents of the questionnaire and the results of the responses are shown in Table5.1.

Table5.1 Questionnaire for curators

No.	Question	Choices & Number of respondents		
		Strongly useful	Useful	Useless
1	Did observing the data help you understand the data?	1	4	0
2	Was it helpful to understand the data by presenting information about the measurement intention and method of the data as well as the data value?	0	5	0
3	Did expressing and recording "Findings" of the graphed results help in understanding the data?	4	1	0
4	Did referencing the recorded graphs and "Findings" help you to gain new "Findings"?	2	3	0
5	Did referencing the recorded graphs and "Findings" help you gain "Learning"?	3	2	0
6	Did referring to the recorded graphs and "Findings" and "Learning" help to generate ideas for improving the exhibition?	1	3	1

7	In addition, please give us your opinions and impressions.	• I could justify what I had sensuously understood using graphs and numerical values. • By accumulating "Findings" and "Learning", I think that it will promote discoveries and grow into information that has great significance for the exhibition. • It would be nice if it were easy to see the changes and different parts on the graph. • It is good to confirm the detailed information (location, measurement time, data value) of each measured value on the graph.

As a result of the questionnaire, as can be seen in the answers to questions 3-5 and the free-form opinions, most curators who participated in the trial experiment evaluated that the software based on KED was useful for their knowledge creation. It was also found that it is expected that knowledge creation will be further promoted by accumulating visualization examples, findings, learning, and improvement ideas of other curators and using them. On the other hand, the trial experience time of the prototype system was about 10 to 15 minutes, so the subjects did not have enough time to observe the data. Therefore, although the answers to the other questions cannot be said to be highly evaluated, it can be judged that the possibilities and expectations were felt. In addition, it is expected that the promotion effect of knowledge creation will be improved by improving the interface of the prototype system in the future, like the improvement opinion shown as a free description opinion. And, using the Curator Agent, it can be expected that discussions and opinions for optimizing the data measured by the sensor agent will be discussed and created as knowledge to be feedback to the sensor agent. In this way, it was confirmed from the evaluation by the museum curator, who is the actual user of the software, that the environment based on KED is effective in promoting knowledge creation.

5.5. Conclusion

It was found by verification using a CA prototype based on a scenario that knowledge can be created by designing processes and interactions based on the concept of knowledge experience. Specifically, the interaction model that guides knowledge creation could be implemented as a practical web application. Then, it was confirmed that the interaction promoted by the Web application forms a knowledge structure that improves the quality of activities (quality of exhibition services). In other words, designing based on the idea of knowledge experience creates a software system that promotes knowledge creation. Curators will be able to expect a better understanding of visitors in the future, adding arbitrary data to the repository for the environment that has been proposed and verified.

When viewed as an application, there is still room for interface improvements to further accelerate the process at each step of CA prototype knowledge creation.

- Collect: To diversify the variation of visualization by making it possible to select the X-axis, visualize the correlation, and specify the stratified variables. Enable reuse (cited/changed visualization) of recorded visualization conditions. Make it possible to express findings in languages other than natural language (applying multi-View Symbol).
- Explore: Make it easier to classify (reference/search) the recorded findings (by the underlying data, the person who created the finding, the date and time when it was recorded, etc.).
- Create: It makes it easier to classify (reference/search) the recorded learning by the underlying findings, data associated with the findings, the person who created the learning, the date and time when it was recorded, etc.).
- Donate: Diversify the method of referencing the knowledge of the operator. The operator can not only refer to the learning and findings related to the idea as the starting point but also specify the findings and learning to search for the idea associated with it.

All of them can be judged as the refinement of functions, and it can be evaluated that the application works well in terms of the basic design for encouraging knowledge creation activities.

In future work, it will be necessary to evaluate the impact of findings and learning gained from knowledge experience on improving the quality of activities and improving the support environment to obtain more appropriate effects. However, the recorded and shared knowledge experience can be edited when applied by other actors so that continuous and cyclical improvement and growth are expected. Furthermore, further improvements will be made by analyzing the nature of more frequently applied knowledge experiences and increasing such knowledge experiences.

In this chapter, the effectiveness of KED was evaluated for the form in which humans create knowledge from the data collected by sensors, and humans use the knowledge created by humans. In the future, it will be necessary to try and evaluate the creation and use of knowledge not only for people, devices, and software but also for any combination. In addition, in this enforcement, findings, learning, and improvement plans are described in natural language, and there is room for improvement to accurately classify and organize their characteristics and meanings. For this, It is conceivable to automatically classify and organize the accumulated knowledge by adding natural language processing and machine learning and to apply the language (for example, multi-view symbol [87, 88]) that expresses them to the expression and visualization of knowledge.

Attempts at CA prototypes are not simply sharing data or providing a data and data analysis environment. It means sharing the data and data analysis environment and the findings and learning gained from the analysis in an adaptable (understandable and editable) state. And it shows the possibility of a new form of knowledge creation called Knowledge Experience. By sharing data, analysis environment, findings, and consideration based on the idea of knowledge experience like the CA prototype, it can be expected to promote interpretation and discovery using the knowledge of multiple people. This will be one of the means to realize the place of Collective Learning [89] to evolve the ability to learn in a group. And through these efforts, it is expected that it will be possible to combine human-computer collaboration freely and continuously obtain high-quality activities and activity results according to the purpose and intention in the future.

Chapter 6

Cooperative Design of Devices and Services to Balance Low Power and User Experience

This chapter shows that knowledge experience design can apply to co-design of system components and user experience. In the case introduced, the findings gained from observing the visitor experience of the curator contributed to the design of the device (energy saving of measuring equipment and improvement of measurement data).

6.1. Introduction

CPS (Cyber Physical Systems) is effective for utilizing data and improving the quality of real-world activities. Adoption of CPS is largely encouraged in the manufacturing industry, but it can also be effective in the service sector. The Smart Museum Project is an initiative to realize a system to monitor and improve museum services by sensing the behavior of visitors with passive sensing devices, and analyzing and inferring the viewing experience of visitors [90]. The system incorporates Knowledge Experience Design (KED). This design methodology focuses on user activities (user experiences) and the underlying knowledge and encourages design decisions that best preserve such knowledge that is useful in maximizing the service value. This chapter presents an application of KED to a system involving co-design of a hardware device and application service that are interdependent, which accomplished power reduction in the device, while preserving the quality of the user experience that is often sacrificed in preference of efficiency and performance.

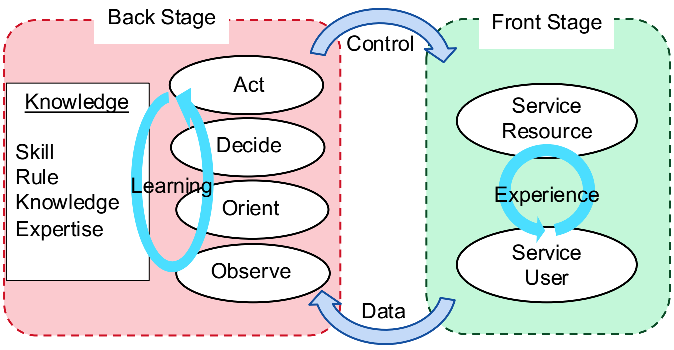


Figure 6.1 Front Stage–Back Stage view of a service

To highlight user experiences in service design, a service can be modeled using a Front Stage and a Back Stage analogy, as depicted in Figure 6.1 [91,92]. The Front Stage represents the experience of the end users of that service, whereas the Back Stage represents the experience of the providers of that service, who will observe the current status, consider improvements, and apply necessary control. In the Back Stage, the context-sensitive control of the Front Stage is generated by a process called Observe-Orient-Decide-Action [93,94]. First, the situation of the Front Stage is observed through collected data. Then, an orientation that best responds to the situation is formed, which leads to a decision, and the corresponding action is executed as a control. In carrying out this process, it is necessary to utilize (learn) knowledge that consists of skills, rules, knowledge, and expertise [5,11].

By designing an information system based on this model, the collected real-world (Front Stage) data is analyzed/recognized in cyberspace (Back Stage) and corresponding knowledge is accumulated. Controlling real-world services based on accumulated knowledge improves the quality of the user experience, just as in a CPS.

It is one of the roles of the museum to analyze and understand the visitor experience, improve the exhibition service, and improve the experience of visitors [78]. The model of the museum service is shown in Figure 6.2. The Smart Museum Project aims to acquire the experiences of visitors as data and control the exhibition based on it. In this case, the control may include, for example, optimizing explanations to visitor interests, adjusting the exhibit hall environment (lighting, temperature, etc.), and providing route guidance to avoid congestion.

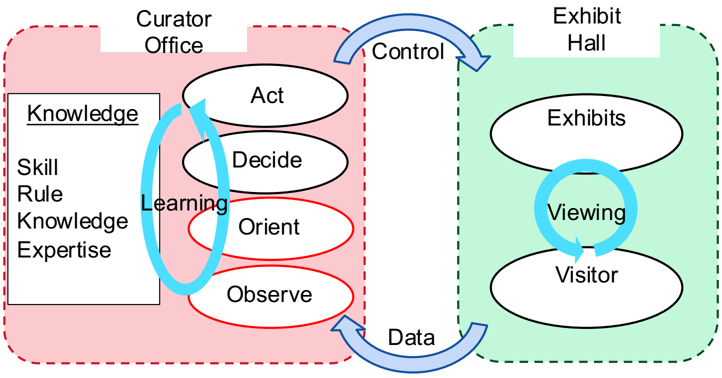


Figure 6.2 The proposed service model of Smart Museum

To design an information system based on this model, criteria for evaluating the collected data and for deciding the control, according to each situation, play an important role. In the museum service of this study, first, it is necessary to identify data types and measurement methods that are effective in controlling the exhibition. Then, the requirements on the system for supporting the Curator's behavioral processes in the observe and orient phases of the process need to be defined. In the context of the target service, the requirements should include the support of Curators to explore and analyze the data collected in the exhibit hall and to engage in learning.

The KED is applied to the design and development of the system. Through the operation of the prototype system based on KED, the accumulation of learning (knowledge) that leads to the control of the exhibition, and the types of data and measurement methods that are useful for the control of the exhibition, will be clarified. The following describes the design and implementation of the Smart Museum prototype system based on the KED. Next, the approaches related to KED are introduced and the characteristics of KED are shown. Then, based on the data measured by the prototype system and the knowledge obtained from the data, the type of the data and the measurement method of the data are considered. Specifically, it is shown that KED contributes to the co-design of systems and services through the issue of power saving in data measurement.

6.2. Curator's Experience Design

Step 1 of the Curator's experience design focuses on the Observe and Orient activities. For Observe, it is necessary to consider the characteristics of museum visitors. The purpose of museum visits varies from person to person but can be broadly classified into (1) Visitors who are willing to spend time watching exhibits for learning (hereinafter referred to as Engaged Visitor); and (2) Visitors who do not expect to spend a lot of time watching the exhibits, for fun (hereinafter referred to as Casual Visitor) [79, 80]. And many visitors can be classified as Casual Visitors [81]. In the past, such surveys were mainly conducted using paper questionnaires. However, it was difficult to collect detailed data, especially from Casual Visitors, because the response behavior was different from the appreciation behavior [81]. There have been several reports of attempts to measure the user experience of visitors in museums by external observation, but most of them adopt VR (Virtual Reality) technology as an exhibition method and record the experience contents in VR [79, 95-102], there is almost no measurement report for the conventional physical exhibition appreciation.

In the Smart Museum Project, the viewing behavior of visitors (mainly for Casual Visitors) is externally observed by sensors, and the Curator grasps the user experience of the visitors.
The model obtained from the above considerations is shown in Figure 6.3.

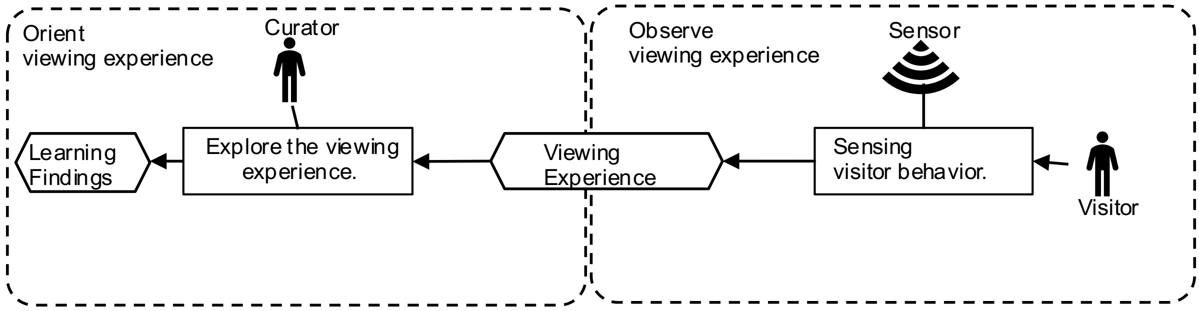


Figure 6.3 Focus on Actor, Activity, input, and outcome in Curator's Experience

Conventional design techniques that focus on data flow (the relationship between input and output data) focus on ensuring that Sensor output specifications and Curator input requirements are consistent. On the other hand, Knowledge Experience based design focuses on the effect of the data output by the Sensor on the quality of the Curator's activities (contents of findings). Step 2 derives the design of a mechanism for reusing information as knowledge in order to improve the quality of the Curator's Experience (Figure 6.4).

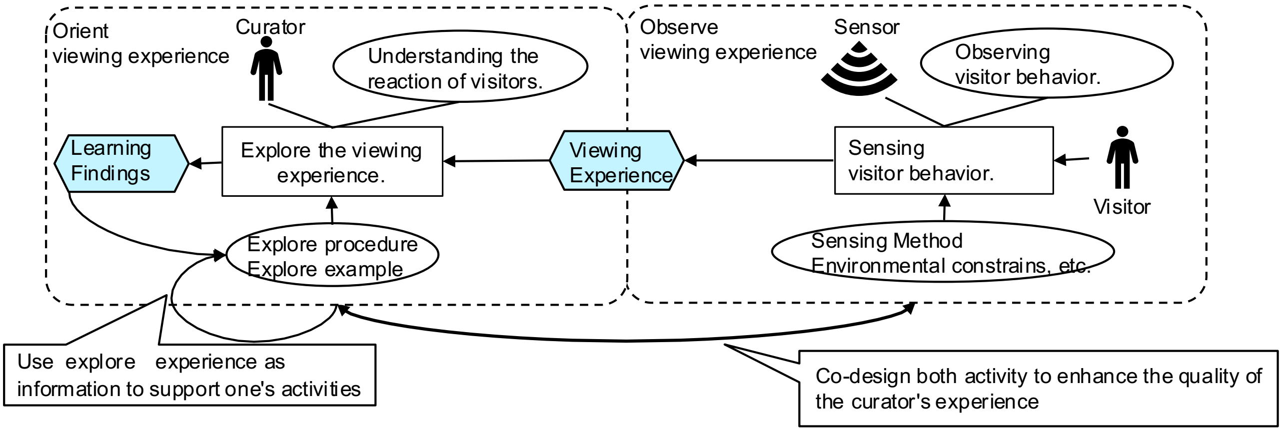


Figure 6.4 Add some elements related to Curator's Experience

The purpose of the Curator's activities in this model is to understand the reaction of visitors, and it is possible to improve the quality of analysis by utilizing analysis procedures and analysis examples. Analysis procedures and examples can be obtained from the Curator activities that have been carried out so far, and the quality of Curator activities can be evaluated by the learning and findings that are the result of the activities. From these facts, it can be seen that Curator's activities and Sensor's activities need to be coordinated because Curator's learning and findings are influenced by the measurement results of visitors by Sensor, which is the input to Curator's activities. In other words, in the design of Sensing visitor behavior, the effect of widening the interval of number measurement is the magnitude of the effect on Curator's learning and findings. This can be evaluated by the equivalent learning and findings before and after widening the interval.

6.3. Related Work: Human-Centered Design and Co-Design

The ideas related to the methods presented in this work are human-centered design and co-design. Human-centered design (ISO9241-210) is the idea of incorporating the user's perspective into the software development process to achieve a usable system [103]. Human-centered design shows the design process and the techniques that can be applied to each process, but the techniques for knowing the user's requirements are general and not shown as specific steps. In the case of the Smart Museum Project, it is necessary to understand the impact of change requests on system components on the user experience and consider the necessary trade-offs. To deal with such cases, a systematic method that incorporates the concept of co-design is required.

The idea of co-design is that the designer makes appropriate design trade-offs for multiple design elements, which is practiced as hardware–software co-design. The hardware–software co-design aims to achieve system-level goals by leveraging the synergies of hardware and software through the simultaneous design of both [104,105]. The idea of hardware–software co-design was mainly targeted at systems on silicon, but efforts are being made to extend it to CPS [105,106]. In co-design for CPS, efforts are being made to coordinate CPS design and CPS service quality, mainly based on objectively (external) measurable results. There is no idea of coordinating the quality of service to end users with the functions that make up CPS from the perspective of user experience, such as human-centered design.

To focus on humans and coordinate systems and user experiences, it is necessary to design proper human–computer collaboration [1]. A prominent problem in human–computer collaboration is that it is difficult for humans to obtain enough information to understand and use the output of computers [2,107]. Communicating instructions and procedures as procedures, rules, and norms is not enough to enable information to guide decisions and actions. It needs to be shared in relation to the underlying grounds, reasons, purposes, and intentions [71]. This discussion is also related to the transparency and explanatory discussion [2,107] of computer calculation results (results of automated learning). Miller's sociological insight into AI's accountability [3] shows that the actions taken are usually explained by goals or intents. It also states the need to explain goals and intentions, as well as calculation results. The same thing has been said in the field of education [8], indicating that an appropriate explanation is required for the recipient to understand and use the information.

The relationship between humans and computers, so far, can be regarded as a battle for initiative between automation by computers and control by humans, and it can be organized that they have created and accumulated information for themselves [1]. In human–computer collaboration, the following items are listed as issues for realizing activities in which humans and computers cooperate: (1) mutual goal understanding; (2) preemptive task co-management (joint management of proactive tasks); (3) shared progress tracking. However, no useful results have been obtained [9].

Introducing initiatives related to human–computer collaboration, user experience is an effort to understand the human perception and response that results from the use of products, systems, and services, as defined in ISO 9241-210. Human–Computer Interaction (HCI) is designed on the assumption that humans can use computers more efficiently. Human-in-the-loop (HitL) is an effort to optimize interpretability by including humans directly in the optimization loop [107]. HitL is designed to involve humans in some decisions and controls in AI systems, centered on machine learning and deep learning [108]. Computer-supported cooperative work (CSCW) is working on how computer systems can be used to support collaboration and coordination [109]. Computer-Mediated Communication (CMC), which is a form of human-to-human communication, via a network computer, has become widespread as a general means of communication, as represented by SNS (Social Networking Service) [110].

The practice of using the information as knowledge to improve the quality of activities has been practiced in the field of Knowledge-Based Engineering (KBE). Verhagen et al. [72] organized and evaluated KBE-related efforts and presented research topics. KBE is a field of research methodologies and techniques for acquiring and reducing product and process engineering knowledge, to reduce product development time and costs. The issues of KBE are as follows: (1) developers need to identify issues and create individual KBE solutions based on custom development processes (ad hoc development); (2) formulations and captured knowledge formulas and actuals to capture design intent Knowledge cannot be utilized because there is no explanation of meaning and context (black box application).

Domain-Driven Design [77] is a method that incorporates the use of knowledge into software system design. Domain-Driven Design (DDD) can be regarded as a method that incorporates the concept of KBS into object-oriented design, which is a software system design methodology. DDD realizes business activities on the software system by incorporating the business rules in the target business area (activity area) to objects. DDD presupposes that business rules can be determined in advance, but in today's diversified values, it is necessary to adopt business decisions to the varying situations. It is necessary to be able to adjust the rules for making decisions according to the situation. This is an analysis that is consistent with the difficulty of applying rules in environments where uncertainty exists, as described by Cummings [5]. In areas where the process is clear as a business activity and the decision-making criteria can be clarified, efforts are underway to capture and utilize the experience related to decision making as knowledge. More flexibility is needed in cases where the standards of value are not always clear or need to be changed (or may change), depending on the context of the activity [5].

In this way, the cooperation between humans and computers has been considered from the one-sided perspective of either humans or computers. There was no perspective on designing collaboration from both human and computer perspectives and creating, accumulating, and sharing information that would be useful (know, understand, and use) for both humans and computers.

The areas of application for CPS are various (living-related automation, transportation, manufacturing, civil infrastructure, and healthcare) and are becoming more and more related to QoL (Quality of Life) [106]. Along with this, there is an increasing need for a coordinated design of systems and user experiences so that computers and humans can mutually understand and utilize the results of their activities to strike a proper balance between the system and the user experience. As a method for co-design in CPS, there is a need for a method for systematically deriving the connection between the system and the service and the method for assessing the impact on the service when the system components are changed. In other words, it is necessary to extend the conventional concept of human-centered design and the concept of collaborative design to include the quality of the user experience provided by CPS, and to organize the design process for that purpose as a method.

In this section, the idea of Knowledge Experience is introduced for this issue. Knowledge Experience focuses on the user experience created by the use case and analyzes the activities that make up the use case and the information necessary for the activity. Based on this analysis, co-design is performed at the level of the system (consisting of HW and SW) and service (realized by the system). This method is characterized by coordinating the trade-offs in designing the components of the system at the user experience design level, leading to appropriate design. This makes it possible to derive the relationship and evaluation method between the impact of system design, such as hardware and software and the quality of user experience.

6.4. Implementation of Smart Museum Prototype

The prototype system consists of (1) a sensor agent that collects viewing experiences, (2) a viewing experience repositories, and (3) an environment (Curator Agent) for Curators to explore and analyze the viewing experience (Figure 6.5).

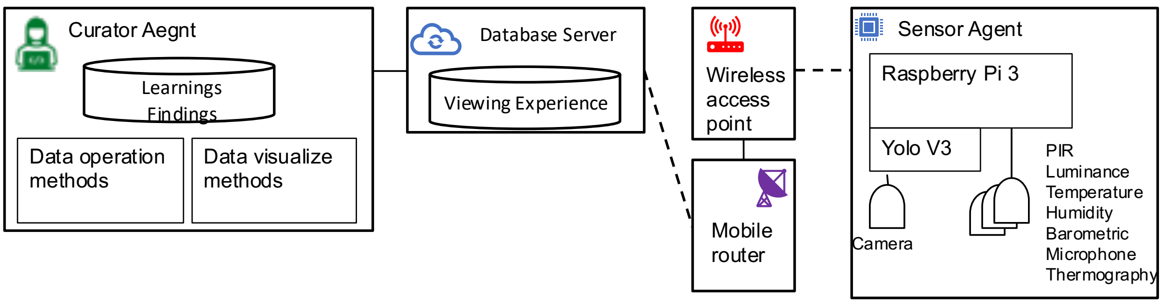


Figure 6.5 Smart Museum Prototype System

1) Sensor Agent: A sensor network, consisting of multiple sensor nodes, will be introduced in the exhibition room to collect viewing experiences, without relying on active involvement. Individual sensor nodes detect and record visitors who are viewing at that location. It also measures and records the conditions of the viewing environment, such as temperature and humidity at that time. In sensing and recording, in consideration of the right to protect personal data, information, such as images and sounds, that can identify individuals is not saved, and

access from the outside is also blocked.

2) Viewing Experience Repositories: Accumulates the viewing experience collected by Sensor Agent and makes it available for Curators to explore and analyze.
3) Curator Agent: Explore and analyze the viewing experience using the datasets and methods shared by the Viewing Experience Repositories.

The prototype system was installed into the museum and started trial operation, as shown in Figure 6.6. Eleven sensor nodes are placed in the exhibition room of the museum and the data from each Sensor Agent are sent to Viewing Experience Repositories, installed at the Data Center via the mobile LTE network, used for exploration and analysis of viewing experience as a knowledge creation activity.

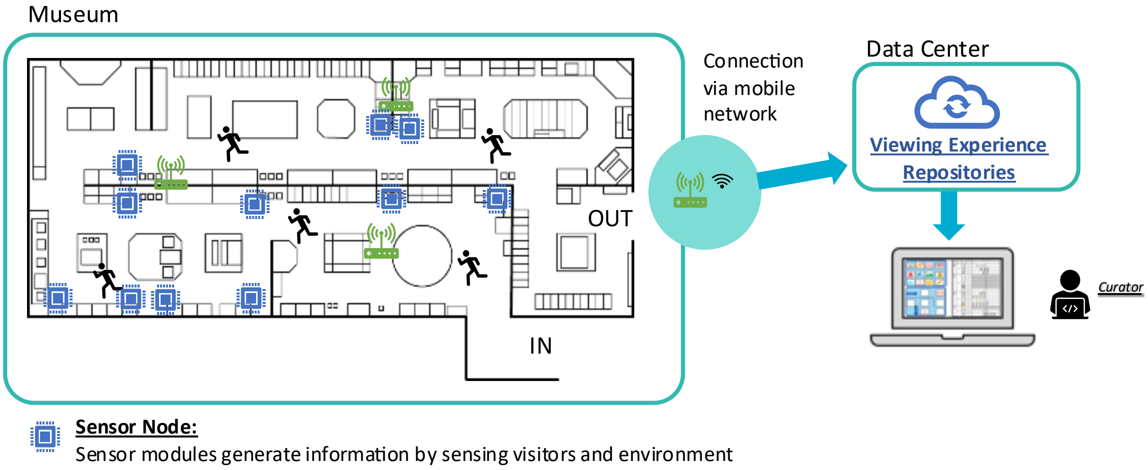


Figure 6.6 Overview of prototype system installed in the museum

The Sensor Agent is built from a camera, a microphone, a PIR (Passive Infrared Ray) sensor, a temperature/humidity/barometric pressure/illuminance sensor, and a Raspberry PI board. Sensors measure visitor behavior and environmental changes at stationary monitoring points to observe the visitor's behavior. The camera image is processed by the image recognition program Yolo [82], to calculate the number of visitors near the sensor node. PIR senses the movement of people to detect if there are visitors near the Sensor Agent. The microphone measures the volume near the Sensor Agent to determine the presence of visitors. The temperature/humidity/barometric pressure/illuminance sensor is used to record the environmental conditions of the visitor's viewing experience and to evaluate the impact of changes in the environmental conditions on the viewing experience. Yolo's process of calculating the number of visitors is programmed to run every 60 s. The reason is that, since the installation location is in the museum exhibition room, it is necessary to prevent the sensor board from generating high heat due to the frequent execution of Yolo.

The data measured by the Sensor Node (Table 6.1) are stored in the Database Server, as a viewing experience for visitors, and is used for exploratory analysis and grasping activities of the viewing experience by the Curator on the Curator workbench. Researchers designed and built these data to meet the museum's requirements and expressed the viewing experience (visitor behavior and viewing environment) based on the data measured.

Table 6.1 Overview of prototype system installed in the museum

Name	Device	Intention of Measurement	Measurement-Method
time	Server	Record date and time of measurement	The server records the time when the data is uploaded.
agent_serial	Sensor Node	Uniquely identify the sensor agent	The unique number (serial number) of the sensor agent is added at the time of data transmission.
temperature	Temperature sensor	Ambient temperature (celsius)	Temperature sensor measurements (measured at 1-min intervals)

Name	Device	Intention of Measurement	Measurement-Method
humidity	Humidity sensor	Abient humidity (%)	Humidity sensor measurements (measured at 1-min intervals)
pressure	Barometric pressure sensor	Atmospheric pressure (bar)	Barometric pressure sensor measurements (measured at 1-min intervals)
luminance	Illuminance sensor	Ambient luminance (lux)	Illuminance sensor measurements (measured at 1-min intervals)
noise.db	Microphone	Ambient noise (dB)	The volume level is recorded by the microphone. (Audio is not collected and conversations are not analyzed or recorded.)
motion	PIR motion sensor	Movement of visitors (%)	It is measured once every 0.5 s with a motion sensor to calculate the probability that a visitor was present in the area in 1 min.
presence	Camera	Number of visitors	Computer the number of people included in a captured image. (A machine learning algorithm is used to recognize people, but the individual is not identified.)

In the Curator Agent, methods for visualizing data and methods for manipulating data are shared to carry out exploratory analysis and grasp activities of the viewing experience by the Curator. In addition, the findings gained as a result of the exploration is recorded and shared. In this way, methods and findings are shared as knowledge to improve the quality of the Curator's activities. This is a design based on the concept of Knowledge Experience.

6.5. Collected Data and Created Knowledge in the Prototype System

Data for evaluation was collected at the Fukushima Museum in Aizuwakamatsu City, Fukushima Prefecture, from 19 June to 2 July 2021. The Fukushima Museum is open from 9:30 am to 5:00 pm, and there are regularly closed days. The number of visitors during this period as recorded at the admission counter and closed days are shown in Table 6.2.

Table 6.2 Number of actual visitors during the experiment period

Date		Number of Visitors
6/19	Sat	83
6/20	Sun	92
6/21	Mon	closed day
6/22	Tue	135
6/23	Wed	243
6/24	Thu	349
6/25	Fri	338
6/26	Sat	85
6/27	Sun	143
6/28	Mon	closed day
6/29	Tue	closed day
6/30	Wed	372
7/1	Thu	356
7/2	Fri	no data

As an example of the data collected, Figure 6.7 and Figure 6.8 show the results of measuring the number of visitors on the days with the highest number of visitors (June 30th) and the days with the lowest number of visitors (June 19th). In this example, four measurement points (sensor nodes) are used for simplification. Sensor nodes are numbered and the node numbers and locations, as well as the measurement range for each node, are shown in Figure 6.9.

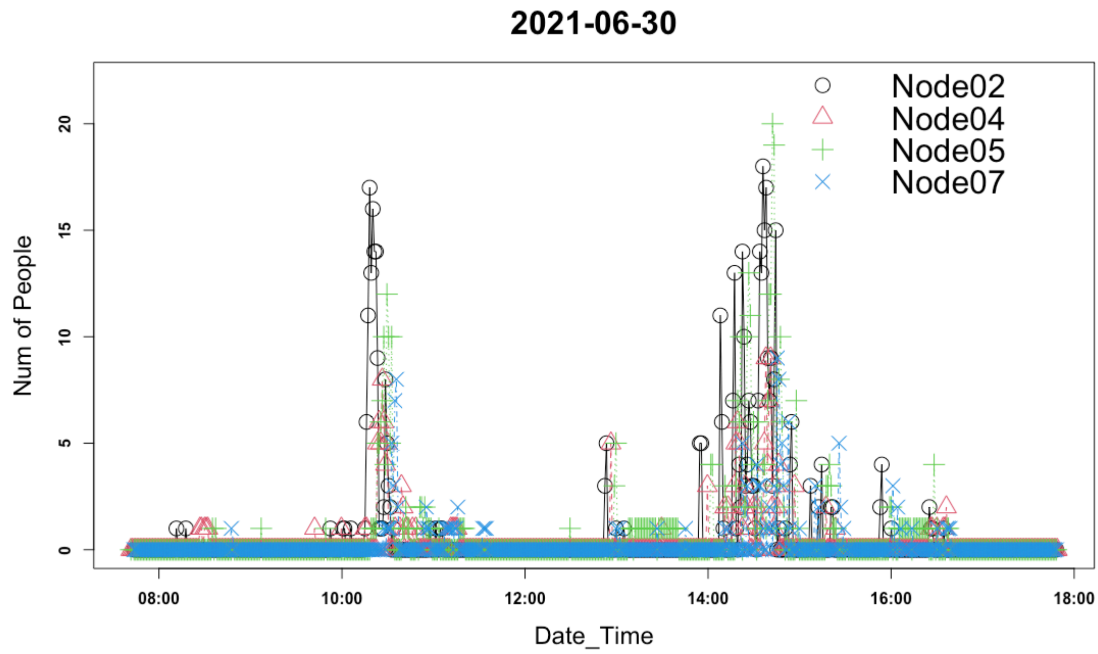


Figure 6.7 Number of visitors detected by the sensor nodes (on 6/30)

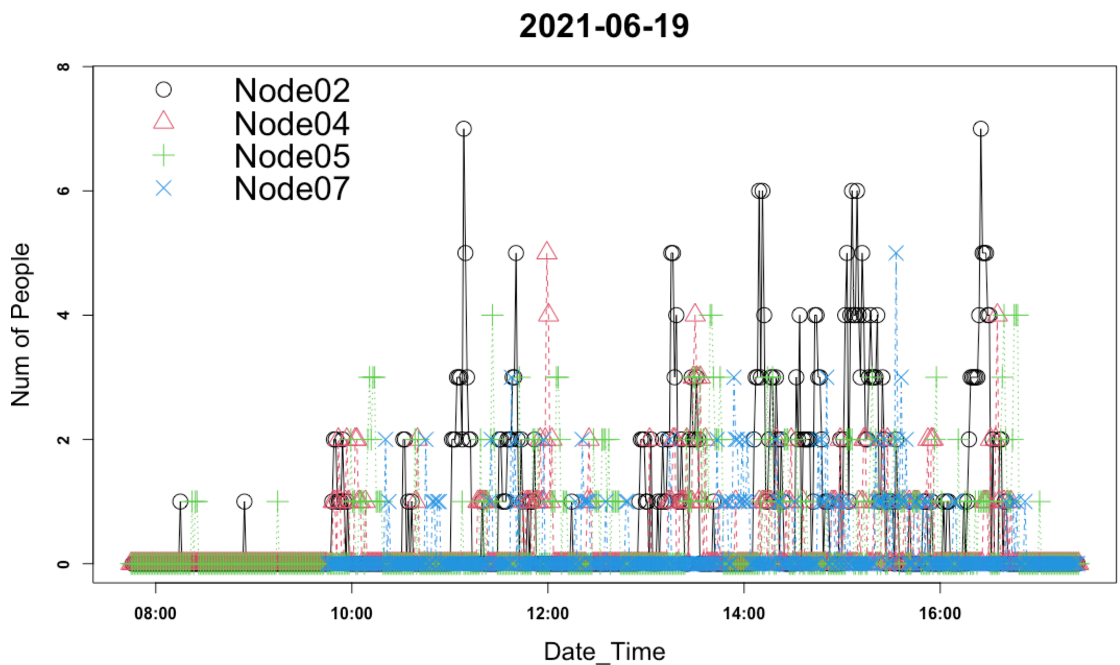


Figure 6.8 Number of visitors detected by the sensor nodes (on 6/19)

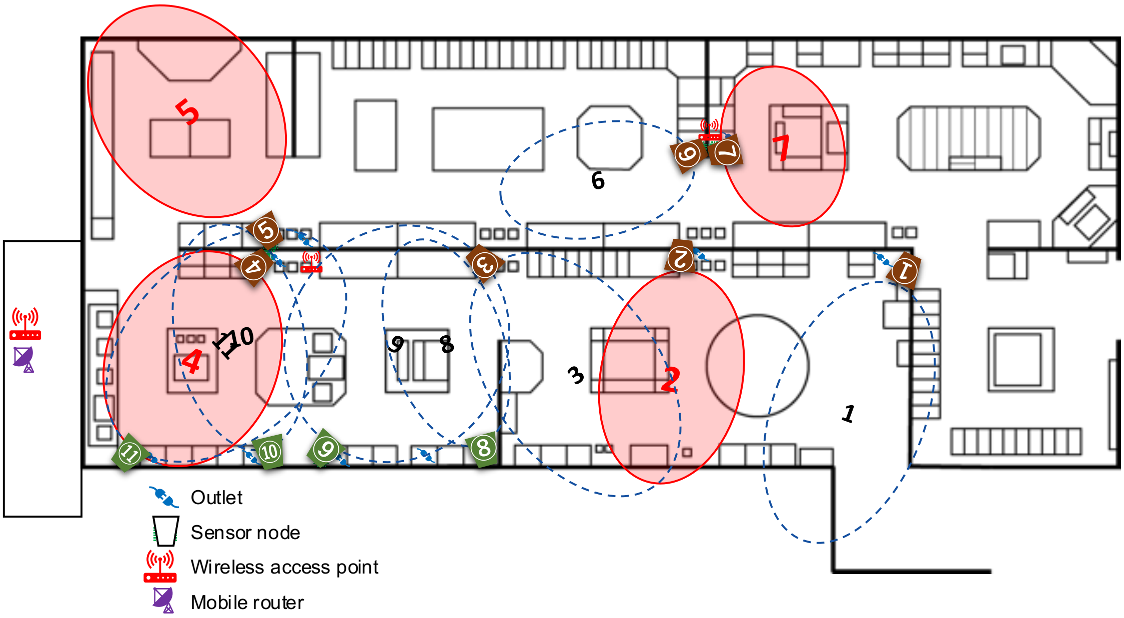


Figure 6.9 Positions of sensor nodes installed at the museum

The number of people measured depends on the sensor node. The number of people measured by Node02 on both days was generally higher than that of other nodes, which indicates that there is a high level of interest in exhibits near Node02. The total number of people measured at each sensor node does not match the number of visitors per day (Table 6.3). This is because there are visitors who were not measured because they passed by without stopping at the place, and visitors who were measured multiple times by the sensor because they stayed at the place to view that area for a longer time. From this data, it is not possible to determine the exact number of visitors who stopped and viewed the exhibits at each location, but it can be interpreted that the visitors who passed by were not interested in the exhibits. In addition, it can be interpreted that visitors who stayed at the place and were measured multiple times are more interested in the exhibits. In this way, by comparing the number of people measured, it is possible to compare the degree of interest of visitors at each measurement location and measurement time.

Table 6.3 Daily total of the actual and detected number of visitors

Date		Number of visitors	Node02	Node04	Node05	Node07
6/19	Sat	83	396	150	249	112
6/20	Sun	92	272	109	272	115
6/21	Mon	closed day				
6/22	Tue	135	175	51	120	52
6/23	Wed	243	393	147	297	129
6/24	Thu	349	622	233	12	230
6/25	Fri	338	758	275	477	253
6/26	Sat	85	267	162	152	105
6/27	Sun	143	419	175	291	179
6/28	Mon	closed day				
6/29	Tue	closed day				
6/30	Wed	372	423	171	406	141
7/1	Thu	356	456	146	358	136
7/2	Fri	no data	225	105	242	82

For the Curator to recognize the difference in the level of interest of visitors at each measurement location and measurement time, it is necessary to aggregate the data to some extent. By aggregating the data measured every minute and every hour, it becomes easier to understand the characteristics (Figure 6.10 and Figure 6.11).

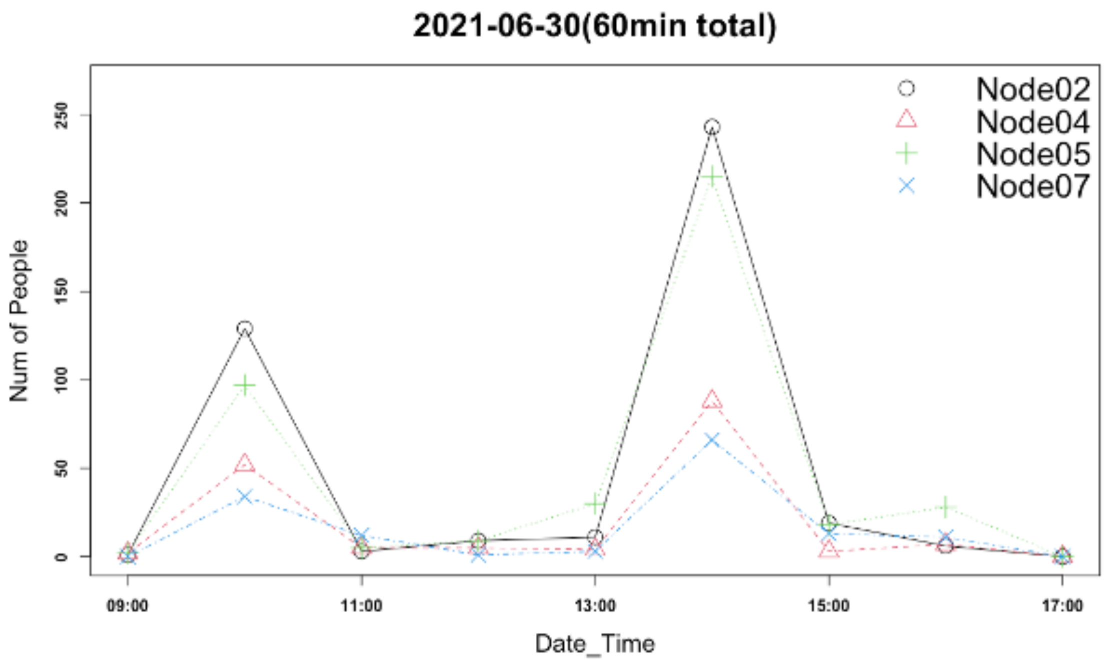


Figure 6.10 Total value every 60 min (6/30)

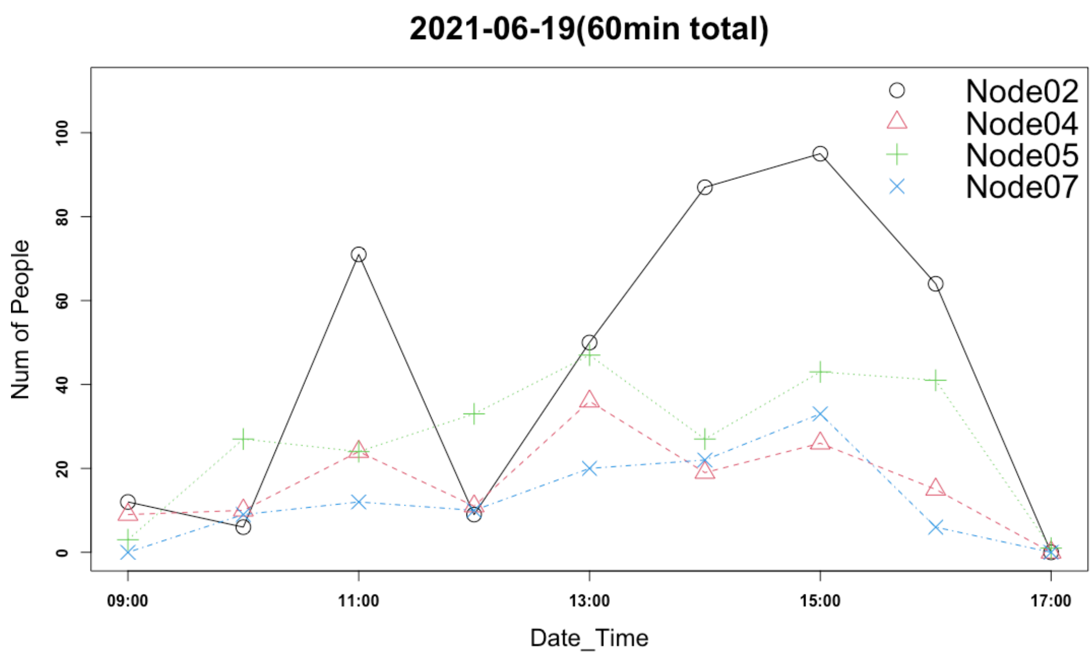


Figure 6.11 Number of visitors detected every 60 min by each sensor node (on 6/19)

Since the placement of sensor nodes were limited by the power outlet locations in the exhibition room, the sensor nodes could not cover the whole area and also overlaps existed Figure 6.9. As has been obtained from similar surveys in the past [111], the Curator's request for the strength of interest is not for each exhibition corner, where multiple exhibits are located, but for individual exhibits. For that purpose, it is necessary to reduce the overlap and omitted area, and be able to identify the object being viewed. In other words, it is necessary to free the placement of the sensor nodes from the limitations imposed by the position of the power outlets.

6.6. Discussion: Loosening the Constraints on the Sensor Node

Based on the data collection by the prototype system and the evaluation of the knowledge gained from the data, it was found that it was required to enable the installation without the constraint of the Outlet. For that purpose, it is necessary to consider how to reduce the power consumption of the sensor node. Before the study, the power consumption of the sensor node was measured by the method shown in Table 6.4.

Table 6.4 Measurement conditions for power consumption

Measuring device	TEXIO PPX 20-5
Measurement method	Measure electric current and voltage at 0.1-s intervals. Calculate the average for every 10 measurements and use the average for 1 s as the measurement result. Measured 300 times (5 min) after stabilized (from about 200 s after power is turned on).

From the measurement result of the power consumption of the sensor node (Figure 6.12), it can be seen that the peak occurs at intervals of about 60 s. Since Yolo is programmed to start at the same timing on the sensor node, it is presumed that the peak will occur due to the execution of Yolo. However, in that case, it is necessary to widen the interval for measuring the number of people, but the effect of widening the interval cannot be judged by the sensor node alone, so the system is used. It is necessary to decide the influence on the user (that is, the change in the quality of the Curator's findings), and it is necessary to have a coordinated design that considers the balance between the two.

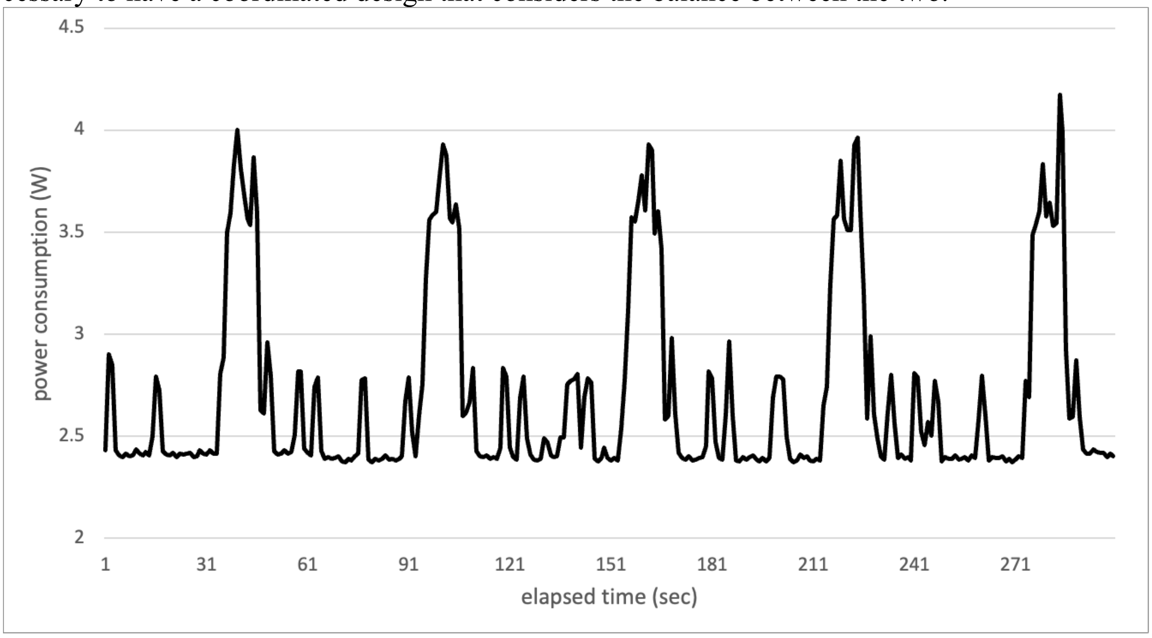


Figure 6.12 Power consumption of a sensor node

Instead of lowering the peak, you can take an approach to reduce power consumption when Yolo is not running by activating the sensor node when Yolo starts up. However, this prototype uses a Raspberry Pi, so it would need to power off and restart. Considering the overhead of powering down, rebooting, and stabilized state, this configuration was determined to be impractical. To confirm the relationship between the occurrence of the peak and the execution of Yolo, the programming was changed to start Yolo every 5 min, and the power consumption meter, in that case, was compared. The power consumption measurement conditions are the same as the above conditions (Table 6.4).

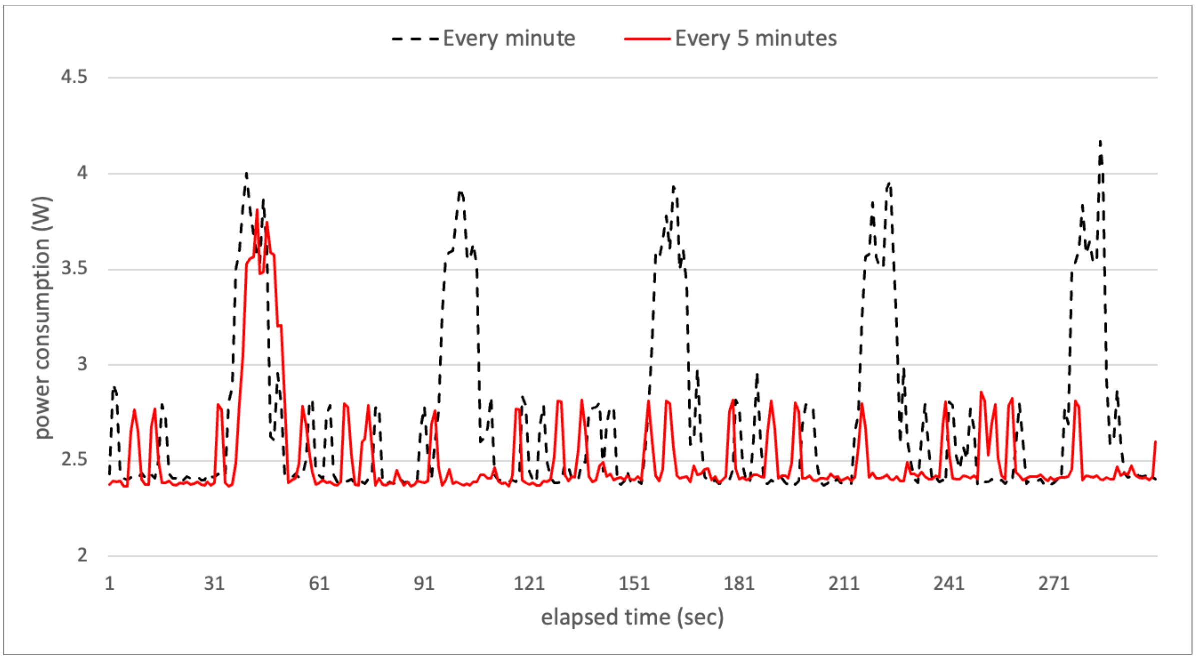


Figure 6.13 Power consumption of sensor node for 1- and 5-min detection intervals

The measurement results are shown in Figure 6.13. The occurrence of the peak was reduced to one, and it was confirmed that the peak was caused by the execution of Yolo. As a result of this experiment, it was found that the average power consumption is 2.71 W when Yolo is started every minute, while it is 2.51 W when it is started every 5 min. It was also found that the average power consumption can be reduced by 0.2 W, 7.5%, by reducing the number of startups of Yolo to 1/5. As organized as a model by KED, the purpose of observation activities using sensor nodes is to grasp the viewing behavior of visitors, and that knowledge is obtained from the number of people per sensor node, calculated by Yolo. Therefore, it is necessary to judge the validity of changing the activation interval of Yolo by balancing it with the knowledge that the Curator can obtain from the data. Specifically, the difference in findings is evaluated by the measured value of the number of people when Yolo is started every minute (1-min value thereafter) and the measured value when the activation interval of Yolo is changed (*n*-minute value thereafter). The hourly aggregates (hereinafter the 1-h aggregated value) calculated using the 2-min to 10-min values were compared to the 1-h aggregates, based on the 1-min values. The correlation coefficient (R) is as shown in Table 6.5.

Table 6.5 Correlation of 1-h aggregate value

Yolo Start Interval	**1 Min**	**2 Min**	**3 Min**	**4 Min**	**5 Min**	**6 Min**	**7 Min**	**8 Min**	**9 Min**	**10 Min**
correlation coefficient (R)	1.000	0.990	0.980	0.962	0.937	0.933	0.917	0.895	0.879	0.837
power consumption (W)	2.71	2.59	2.54	2.52	2.51	2.50	2.50	2.49	2.49	2.49
reduction rate (%)	0.00	4.61	6.15	6.92	7.38	7.79	7.91	8.07	8.20	8.30

1 min and 5 min are actual measurement values. Other values are estimates interpolated from the 1 min and 5 min values.

The difference in the number of people measured for each time zone is compared using the value obtained by summing up 1-h aggregated value for each day (hereinafter referred to as the daily aggregated value). Figure 6.14 is a graph of daily aggregated values using the 1-min, 3-min, 4-min, 5-min, and 7-min value for sensor node 5. As the measurement interval increases, the range of change decreases. Up to the 4-min value, the same tendency as the 1-min value can be grasped, and the range of change between the 5-min value and the 7-min value becomes gradual, making it difficult to grasp the tendency.

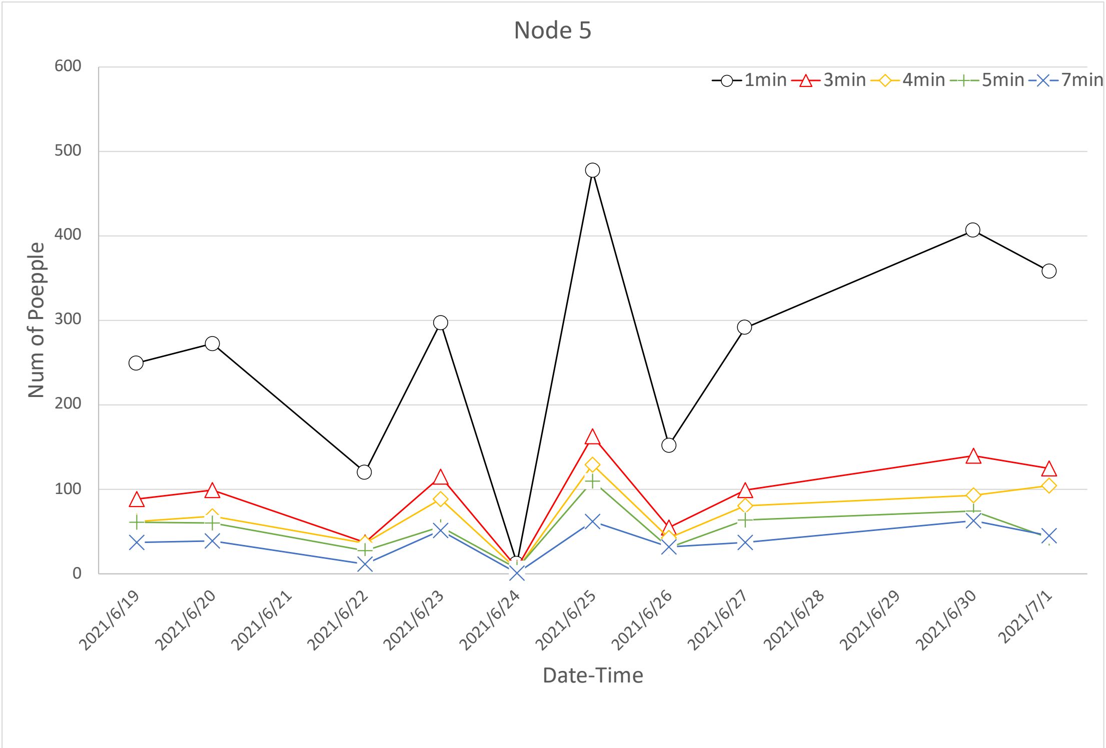


Figure 6.14 Number of visitors detected with different measurement intervals

Furthermore, the ease of grasping the tendency of the number of people measured for each sensor node was evaluated using the 1-to-7-min values (Figure 6.15).

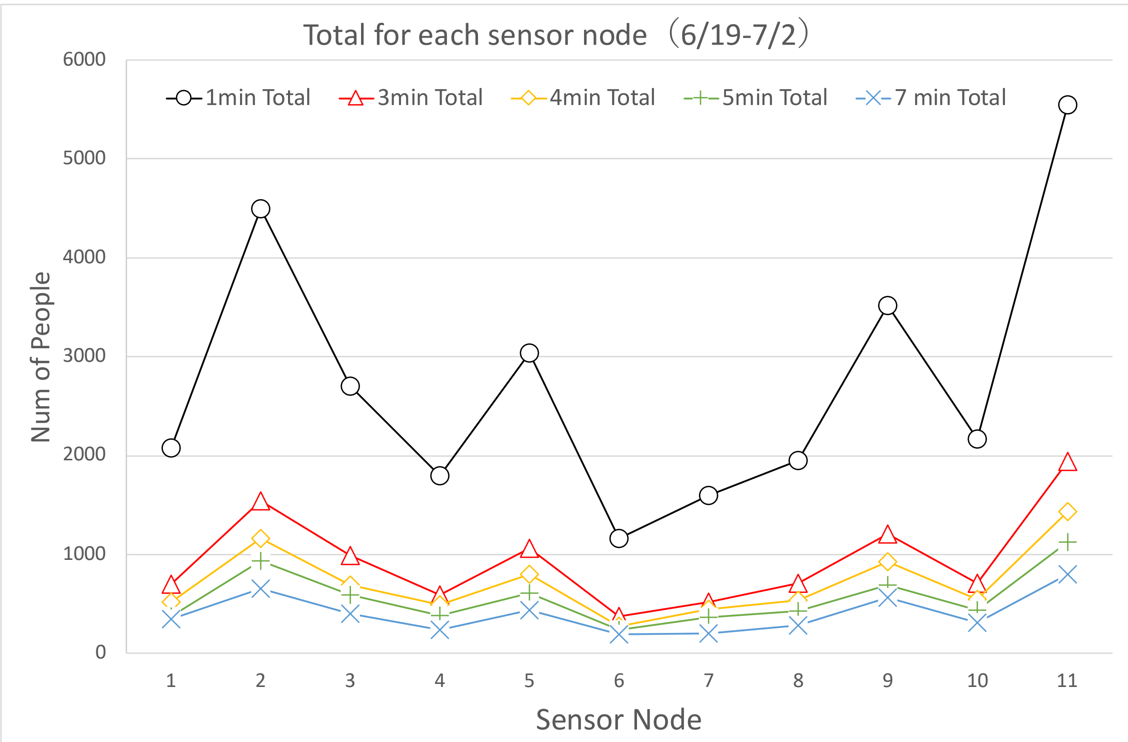


Figure 6.15 The tendency of the number of visitors measured for each sensor node

In this case as well, as the measurement interval increases, the range of change for each time zone becomes smaller, but up to the 4-min value, the same tendency as the 1-min value can be grasped. However, it is difficult to grasp the tendency of the 5-min and 7-min values because the range of change is gradual. From this result, it can be determined that setting the boot interval from 4 minutes to 5 minutes is appropriate when adjusting the boot interval of Yolo to reduce the power consumption of the sensor node. In this way, the knowledge gained by exploratory analysis of the data measured by the sensor node can be expected to improve the measurement method of the sensor node.

6.7. Conclusion

From the prototype system of the Smart Museum, it was found that even if the image analysis program execution interval was changed from 1 min to 5 min to measure the number of visitors, it would not have a significant effect on the Curator's knowledge acquisition. This is useful as a finding on the relationship between the design of system devices (sensor nodes) and the experience of system users (Curators). With this knowledge, it is possible to reduce the power consumption of the sensor node to 92.6%, by changing the data measurement interval from the 1-min interval to the 5-min interval, without affecting the Curator.

This shows that the knowledge gained by the Curator with exploratory analysis of the data from the sensor node can be used to improve the measurement method of the sensor node. In other words, the Curator's experience and the design of system functions could be coordinated. This is the result of designing the measurement of data by the sensor, not as an interface between physical space and cyberspace, but as an activity (Observe) necessary for knowledge creation by a Curator, and relating it to the purpose and intention of the activity. The method that led to this perspective is KED. Thus, an approach that evaluates the quality of the user experience, not just numerical indicators, is effective in designing a form of CPS that provides services to end users.

This achievement can be evaluated not only in terms of reducing the power consumption of the sensor node, while maintaining the quality of the Curator's activities, but also in terms of reducing the amount of data that the sensor node needs to process. By reducing the amount of data processed by the sensor node, it is possible to simplify (Raspberry Pi 3 to Raspberry Pi Zero) the board computer installed in the sensor node. This makes it possible to further reduce the power consumption and size of the sensor node. In addition, further power saving can be expected to be driven by a battery, and the sensor node is not restricted to the position of the outlet in the exhibition room, so it becomes possible to measure the behavior of visitors at any place and measurement range. This will further improve the quality of the Curator's activities. On the other hand, if it is battery-powered, it is expected that it will be necessary to replace the battery regularly and charge the battery. As future work, it is necessary to conduct experiments that combines power consumption and battery capacity and incorporate activities, including system operation, into the KED.

In addition, to reduce power consumption approaches, using state-of-the-art electronic devices and intelligent sensors that can manage energy, can be considered [112]. In the prototype system, the sensor node is implemented with the configuration of a relatively inexpensive part that is widely used. In this way, resources, such as budget, are also important considerations for proper co-design, but in KED, they can be included in the design as constraints included in the purpose and intention of the activity.

In the Smart Museum project, we applied the idea of knowledge experience to hardware–software co-design and tried it as a design method, to optimize the quality of the system (consisting of HW and SW) and the service (achieved by the system). In the case of power saving for the sensor nodes, it was confirmed that it is possible to derive a method to understand and evaluate the effect of changes in system components on services by designing based on Knowledge Experience. It is expected that a system that optimizes customer service and improves the customer experience by acquiring customer behavior with a device, such as IoT, and analyzing the data will become more familiar as an application example of CPS.

Chapter 7

Conclusions and Future Work

First, the dissertation proposed a model for designing knowledge-driven human-computer co-creation environments that focuses on sharing knowledge created by human/computer activities and their reutilization. Second, the work proposed a novel software design method, called Knowledge Experience Design, for developing systems for human-computer co-creation based on the proposed model. It demonstrated that software based on knowledge experience design could in effect facilitate knowledge creation. Furthermore, the dissertation demonstrated the application of Knowledge Experience Design to the cooperative design of system-wide user experience and component device design. (Figure 7.1)

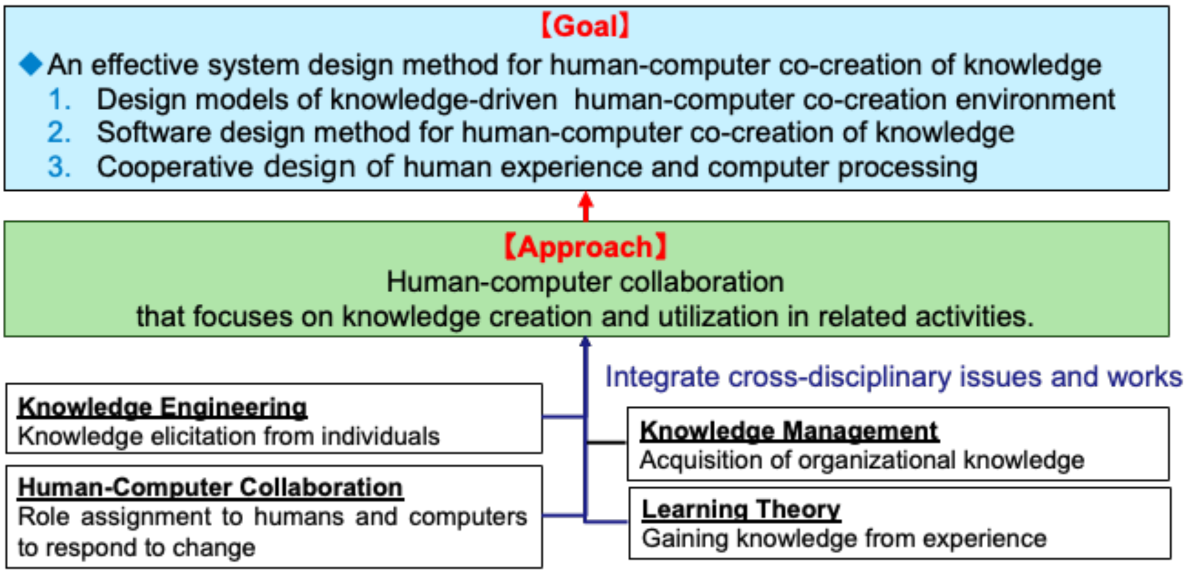


Figure 7.1 Summary of dissertation

The motivation of this work was an interest in the human-computer co-creation of knowledge. As computer automation increases, the difficulty of humans understanding and using the results presented by computers has become an issue. This issue (in other words, the difficulty of knowledge representation and knowledge sharing) has been addressed in the areas of knowledge engineering, knowledge management, and learning theory. However, traditional approaches (such as knowledge acquisition and knowledge elicitation) are expensive and inadequate in quality. As a result, they have been a major barrier to the sharing and using knowledge in an organization.

The proposed method is based on an original cross-disciplinary approach based on combining knowledge engineering, knowledge management, and learning theory to the knowledge life cycle and proposes an approach for developing effective human-computer co-working environments. The dissertation provides new insights into an important topic in the field.

In this way, software based on KED contributes to creating knowledge, coordinating multiple activities, and improving the quality of those activities. Moreover, the actors in those activities can be treated the same way, whether they are humans or computers. In other words, KED contributes to realizing an environment where humans and computers can grow and collaborate. This dissertation introduced an environment for understanding and creating knowledge for museum curators as KED-based software. This environment supports curators' knowledge creation. Furthermore, curators will be able to expect a better understanding of visitors in the future, adding arbitrary data to the repository for the environment that has been proposed and verified.

In the future, it is conceivable to add agents that create new knowledge by calculation (ex., statistics, optimization, machine learning, artificial intelligence technology) based on the shared knowledge. In addition, by incorporating semantic intelligence technology [113], it will be possible to mutually use a wide range of knowledge, such as linking with existing AI/Machine-Learning-Systems. Through these efforts, it is expected that humans and computers will utilize the results of their mutual activities on an equal footing and enhance the environment by creating new value.

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Appendix A: Literature Research Paper Search Results and Selection Decisions

- Literature Group Aa
  - Scopus Search Criteria:

    TITLE-ABS-KEY ("Knowledge Engineering" AND "Knowledge Management" AND "Literature Review") AND (EXCLUSIVE (PUBYEAR , 2020)
  - Top 10 Cited Papers

ID	Article	Cited by	Note
Aa01	Liao [46]	324	
Aa02	Benbya et al. [15]	165	
Aa03	Hung et al. [16]	161	
Aa04	Kim and Lee [17]	90	
Aa05	Anantatmula and Knungo [18]	82	
Aa06	Gavriova and Andreeva [47]	57	
-----	Balaid et al. [24]	37	Selected as Ab10
Aa07	Evangelists and Durst [38]	19	
Aa08	Clark [19]	13	
----	V.S.Anantatmula, S.Kanungo, Modeling enablers for successful KM implementation, Journal of Knowledge Management. (2007)	9	Excluded Duplicate with Aa05
Aa09	Rickenberg et al. [20]	8	
----	S.Rautenberg, A.V.Steil, J.L.Todesco, Knowledge model for mapping knowledge management instruments and knowledge engineering computational agents, Perspectivas em Ciencia da Informacao. 16 (3) (2011) 26-46.	7	Excluded English version not available
----	L.Yang, M.Frize, R.C.Walker, C.Catley, Towards ethical decision support and knowledge management in neonatal intensive care, Annual International Conference of the IEEE Engineering in Medicine and Biology – Proceeding. (2004) 3420-3423.	5	Excluded Theme mismatch
Aa10	Van Waveren et al. [35]	4	

- Literature group Ab
  - Scopus Search Criteria:

    TITLE-ABS-KEY ("Knowledge Engineering" AND "Knowledge Management" AND " Literature Review") AND (EXCLUSIVE (PUBYEAR , 2020)
  - Latest 1 0 papers reported by the end of 2019

ID	Article	Cited by	Note
----	N.Johansson, S.Svensson, Review of the Use of Fire Dynamics Theory in fire Service Activities, Fire Technology. 55 (1) (2019) 81-103.	1	Excluded Theme mismatch
Ab01	Konno and Iijima [21]	0	
Ab02	Hannah and Simeone[49]	0	
Ab03	Hakim and Sensuse [22]	1	
Ab04	Shikhli and Hammad [23]	0	
----	T.Gavrilova, M.Kubelskiy, Knowledge management specification: Building an ontology to get a shared understanding, Proceedings of the European Conference on Knowledge Management. ECKM 2 (2018) 1177-1180.	0	Excluded English version not available
Ab05	Twongyirwe and Lubega [31]	0	
Ab06	Pesquita et al. [50]	0	
Ab07	Mafereka and Weinberg [36]	0	
Ab08	Bourguin and Lewandowski [51]	1	
Ab09	Freitas et al. [48]	2	
Ab10	Balaid et al. [24]	37	

- Literature group Ba
  - Scopus Search Criteria:

    TTITLE-ABS-KEY (("Learning") AND ("Knowledge Engineering" OR "Knowledge Management") AND ("Literature Review")) AND (EXCLUDE (PUBYEAR , 2020))
  - Top 10 Cited Papers

ID	Article	Cited by	Note
----	W.Buntine, A guide to the literature on learning probabilistic networks from data, IEEE Transactions on Knowledge and Data Engineering. 8 (2) (1996) 195-210.	287	Excluded Theme mismatch
Ba01	Scarborough and Swan [25]	176	
----	Benbya et al. [15]	165	Selected as Aa02
----	Hung et al. [16]	161	Selected as Aa03
Ba02	Cao et al. [39]	156	
Ba03	Fazey et al. [42]	138	
Ba04	Revere, et al. [32]	118	
Ba05	Duru et al. [43]	113	
Ba06	Schneckenberg [26]	109	
Ba07	Bryson et al. [33]	99	
Ba08	Brachos et al. [27]	98	
Ba09	Venkitachalam and Busch [52]	81	
Ba10	Ordóñez et al. [28]	69	

- Literature Group Bb
  - Scopus Search Criteria:

    TITLE-ABS-KEY (("Learning") AND ("Knowledge Engineering" OR "Knowledge Management") AND ("Literature Review")) AND (EXCLUDE (PUBYEAR , 2020))
  - The 10 most recent papers reported by the end of 2019

ID	Article	Cited by	Note
Bb01	Roy [40]	0	
Bb02	Clewley et al. [53]	0	
Bb03	Jha & Karen [41]	0	
Bb04	Meher and Misara [29]	0	
Bb05	Sensuse and Bagustari [54]	0	
Bb06	Sanguankaew and Ractham [44]	2	
Bb07	Rashid et al. [37]	3	
Bb08	Ahmad and Karim [30]	1	
Bb09	Dreyer et al. [45]	2	
Bb10	Ibragimova and Korjonen [34]	2	

Appendix B: Content classification of the main 40 papers (based on full-text peer-reviewed results)

ID	Article	Concept	Proposal	Application	Appl.Domain Dependent	Appl.Domain Independent
Aa01	Liao [46]	✓	✓			✓
Aa02	Benbya et al. [15]	✓		✓		✓
Aa03	Hung et al. [16]	✓		✓	✓	
Aa04	Kim and Lee [17]	✓		✓		✓
Aa05	Anantatmula and Knungo [18]	✓				✓
Aa06	Gavriova and Andreeva [47]	✓	✓			✓
Aa07	Evangelists and Durst [38]	✓			✓	
Aa08	Clark [19]	✓				✓
Aa09	Rickenberg et al. [20]	✓	✓			✓
Aa10	Van Waveren et al. [35]	✓				✓
Ab01	Konno and Iijima [21]	✓				✓
Ab02	Hannah and Simeone [49]	✓	✓			✓
Ab03	Hakim and Sensuse [22]	✓		✓	✓	✓
Ab04	Shikhli and Hammad [23]	✓	✓	✓	✓	✓
Ab05	Twongyirwe and Lubega [31]	✓	✓	✓	✓	✓
Ab06	Pesquita et al. [50]		✓			✓
Ab07	Mafereka and Weinberg [36]			✓	✓	
Ab08	Bourguin and Lewandowski [51]	✓	✓			✓
Ab09	Freitas et al. [48]	✓				✓
Ab10	Balaid et al. [24]	✓				✓
Ba01	Scarborough and Swan [25]	✓				✓
Ba02	Cao et al. [39]	✓		✓	✓	
Ba03	Fazey et al. [42]	✓		✓	✓	
Ba04	Revere, et al. [32]	✓			✓	
Ba05	Duru et al. [43]	✓			✓	
Ba06	Schneckenberg [26]	✓	✓			✓
Ba07	Bryson et al. [33]	✓				✓
Ba08	Brachos et al. [27]	✓				✓
Ba09	Venkitachalam and Busch [52]	✓	✓			✓
Ba10	Ordóñez et al. [28]	✓			✓	
Bb01	Roy [40]	✓			✓	
Bb02	Clewley et al. [53]	✓	✓		✓	
Bb03	Jha and Karen [41]	✓			✓	
Bb04	Meher and Misara [29]	✓				✓
Bb05	Sensuse and Bagustari [54]	✓				✓
Bb06	Sanguankaew and Ractham [44]	✓			✓	✓
Bb07	Rashid et al. [37]	✓	✓		✓	
Bb08	Ahmad and Karim [30]	✓				✓
Bb09	Dreyer et al. [45]	✓			✓	
Bb10	Ibragimova and Korjonen [34]	✓			✓	

Appendix C: Organizational knowledge creation process the main 40 papers focused on

ID	Article	I-Learn	O-Learn	Externalize	Formalize	Organize	Sharing
Aa01	Liao [46]		✓			✓	
Aa02	Benbya et al. [15]		✓			✓	✓
Aa03	Hung et al. [16]		✓			✓	
Aa04	Kim and Lee [17]		✓			✓	
Aa05	Anantatmula and Knungo [18]		✓			✓	
Aa06	Gavriova and Andreeva [47]		✓	✓		✓	
Aa07	Evangelists and Durst [38]		✓			✓	
Aa08	Clark [19]		✓			✓	✓
Aa09	Rickenberg et al. [20]		✓			✓	✓
Aa10	Van Waveren et al. [35]		✓			✓	✓
Ab01	Konno and Iijima [21]		✓				
Ab02	Hannah and Simeone [49]		✓	✓	✓	✓	✓
Ab03	Hakim and Sensuse [22]		✓			✓	
Ab04	Shikhli and Hammad [23]		✓			✓	
Ab05	Twongyirwe and Lubega [31]		✓				✓
Ab06	Pesquita et al. [50]					✓	✓
Ab07	Mafereka and Weinberg [36]		✓				✓
Ab08	Bourguin and Lewandowski [51]		✓	✓		✓	
Ab09	Freitas et al. [48]		✓			✓	
Ab10	Balaid et al. [24]		✓			✓	
Ba01	Scarborough and Swan [25]		✓				
Ba02	Cao et al. [39]		✓			✓	✓
Ba03	Fazey et al. [42]		✓			✓	✓
Ba04	Revere, et al. [32]					✓	✓
Ba05	Duru et al. [43]		✓			✓	✓
Ba06	Schneckenberg [26]		✓			✓	✓
Ba07	Bryson et al. [33]		✓			✓	
Ba08	Brachos et al. [27]		✓			✓	✓
Ba09	Venkitachalam and Busch [52]		✓	✓		✓	✓
Ba10	Ordóñez et al. [28]		✓			✓	
Bb01	Roy [40]		✓			✓	✓
Bb02	Clewley et al. [53]		✓	✓			
Bb03	Jha and Karen [41]		✓			✓	
Bb04	Meher and Misara [29]		✓			✓	
Bb05	Sensuse and Bagustari [54]		✓	✓	✓	✓	✓
Bb06	Sanguankaew and Ractham [44]		✓			✓	
Bb07	Rashid et al. [37]		✓			✓	✓
Bb08	Ahmad and Karim [30]		✓			✓	✓
Bb09	Dreyer et al. [45]		✓			✓	
Bb10	Ibragimova and Korjonen [34]		✓			✓	✓

Appendix D: Processes that the main 40 papers and the literature that the main 40 papers surveyed focus on (total sum of number of literatures for each phase)

ID	Article	Cite	I-Learn	O-Learn	Externalize	Formalize	Organize	Sharing
Aa01	Liao [46]	95	1	95	24	2	82	52
Aa02	Benbya et al. [15]	39		39	3		36	25
Aa03	Hung et al. [16]	47		47	2		47	3
Aa04	Kim and Lee [17]	64	7	64	13	1	61	12
Aa05	Anantatmula and Knungo [18]	37		37	3		32	7
Aa06	Gavriova and Andreeva [47]	73	13	72	35	3	30	10
Aa07	Evangelists and Durst [38]	66		62		1	59	38
Aa08	Clark [19]	64	3	58	9		46	27
Aa09	Rickenberg et al. [20]	68	2	62	20	2	60	16
Aa10	Van Waveren et al. [35]	34		34	1		27	16
Ab01	Konno and Iijima [21]	56		54				
Ab02	Hannah and Simeone [49]	51		47	18	12	13	3
Ab03	Hakim and Sensuse [22]	18		15			15	7
Ab04	Shikhli and Hammad [23]	15		12	4		13	
Ab05	Twongyirwe and Lubega [31]	40	3	40	2		4	5
Ab06	Pesquita et al. [50]	31					17	5
Ab07	Mafereka and Weinberg [36]	17		15	5		6	10
Ab08	Bourguin and Lewandowski [51]	26		25	20	20	21	1
Ab09	Freitas et al. [48]	26		8	6		25	6
Ab10	Balaid et al. [24]	128		119	58	1	108	37
Ba01	Scarborough and Swan [25]	40	3	40	2		6	11
Ba02	Cao et al. [39]	82	21	68	15	1	21	40
Ba03	Fazey et al. [42]	131	24	122	44	6	45	21
Ba04	Revere, et al. [32]	45	16	13	22		23	41
Ba05	Duru et al. [43]	174	30	167	11	8	5	28
Ba06	Schneckenberg [26]	30	7	16	2		2	16
Ba07	Bryson et al. [33]	166	3	170	1		9	6
Ba08	Brachos et al. [27]	62	4	57	13	1	2	13
Ba09	Venkitachalam and Busch [52]	104		103	52	12	10	21
Ba10	Ordóñez et al. [28]	31		31				
Bb01	Roy [40]	70		68	8	2	67	6
Bb02	Clewley et al. [53]	28	1	3	24		3	
Bb03	Jha and Karen [41]	70		56			54	1
Bb04	Meher and Misara [29]	61		56	8		56	6
Bb05	Sensuse and Bagustari [54]	28	2	26	16	7	10	25
Bb06	Sanguankaew and Ractham [44]	98	4	83	14		83	7
Bb07	Rashid et al. [37]	148	3	138	22	5	134	41
Bb08	Ahmad and Karim [30]	114		108	9	1	102	91
Bb09	Dreyer et al. [45]	124		117	1		117	1
Bb10	Ibragimova and Korjonen [34]	20		17			18	20