Chapter 3
A Mixed Reality-based Emotional Interactions and Communications for Manufacturing Skills Training

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Abstract In recent years, Japanese manufacturing industry has entered a very competitive era due to globalization and to the concept of manufacturing the right thing at the right place. At the same time, manufacturing in Japan is changing from a conventional mass production and perpendicular work division system to a high-precision, small-lot, multi-variety manufacturing system. In addition to this, the need and opportunity for face-to-face contact between colleagues has been drastically reduced as a result of factory and office automation. This means that human functions that are a result of human contact and relationships are being replaced by automated systems. This transfer of relations from human to machine systems causes individuals to be isolated in the process of their work. Therefore, appropriate staff-training programs with communications based on a long-term viewpoint are needed to create and transfer the skill/technology. However, due to the financial, manpower, and time constraints caused by the present tough economic conditions, it is difficult for small and medium-sized industries to organize good training programs. In reality, more than half of small and medium-sized industries implement on-the-job training, video libraries, technical documents, and the like in their training programs. Nevertheless, these time-consuming and inefficient methods do not make it easy to obtain the high-level skill necessary to be a skilled technician. This chapter considers some reasons for difficulties in skills transfer and human resource development, and addresses a new mixed reality-based job training and human resource development for skilled foundry workers. This chapter also looks at tacit knowledge, coherence in knowledge, and action in manufacturing.

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3.1 Introduction

In the Japanese manufacturing industry, the hollowing out of industry due to the transfer of production centers overseas is having a serious effect on areas where industry is concentrated. In particular, in the core manufacturing technology industries which have supported the manufacturing industry to date, the deterioration in skilled labor is a concern. Also, with an aging population and young people avoiding going into the manufacturing industry, finding new staff/apprentices is becoming difficult, and consequently the Japanese manufacturing industry is facing a crisis. In order to continue the design and manufacture of high-added-value products in the future, the passing down of core manufacturing technology and skilled labor as well as the creation of knowledge is indispensable.

As an example, in the Japanese casting and product forming industry, a high level of international competitiveness has been maintained by rationalizing design and production processes, improving productivity and yield rates, and achieving shorter delivery times, as well as passing on technology and skills, and solving problems such as environmental issues. However, the product forming industry is almost totally comprised of small and medium-sized companies, and sub-contracting transactions are frequent, so at present the management situation is weak. In order to strengthen the product forming industry in Japan in the future, it is important that the technology and skills accumulated to date are further expanded by research and development, unique technologies are established and strengthened, technologies and skills are transferred, human resources are trained to use information and communication technology (ICT), and so on.

Therefore, this chapter describes the acquisition of manufacturing knowledge and human resources training by sharing a “ba” (place) for the application of multimedia technology, virtual reality (VR) technology, *etc.* [1, 2]. In particular, a system is described that uses a combination of a three-dimensional visualization system, created using VR/AR technology, and a force-sensing display device, created using robot technology, to enable not only the visual effect to be obtained, but also to obtain a sense of the force required in casting. It does this in combination with the communication between the engineer and skilled operative. By adding annotation and so on to the space in which a model is displayed in VR space, technical information can be shared, communication between engineer and skilled operatives promoted, and embodied knowledge can be acquired. Also, new experiments in operational support for elderly and female workers using VR technology are described.

3.2 Skills Transfer

3.2.1 Present Situation and Problem Points Regarding Methods of Skills Transfer

As the pace of technical change becomes faster and competition between companies becomes more severe, it is necessary for each company to try to learn faster than the other. Therefore, the number of companies undertaking knowledge management, such as knowledge sharing based on organizational learning theory, knowledge transfer, etc., is increasing, advanced technologies are being recorded in manuals, and information databases using ICT are being introduced. However, as the division of labor in manufacturing sites increases, obstacles to information sharing arise, such as the attitude "as long as it follows the manual, this is accurate enough for my work," and not much thought is given even though accidents occur or defective products are produced. Therefore, there is a danger that knowledge management, which aims to share knowledge and skills among members of an organization in order to improve the rate of learning, can have the opposite effect and actually hinder the nurturing of skilled operatives. Also, if too much reliance is placed on knowledge accumulated in databases within the company, the opportunities for problem solving on one's own reduce. Therefore, by making knowledge sharing easier in order to quickly develop human resources capable of raising efficiency, learning by experience is hindered, so when problems occur it is not possible to quickly respond to them. This leads to the dilemma that knowledge sharing can result in higher costs [3].

A skilled worker is one that within a specific field has both specialist training and practical experience, has acquired special skills and knowledge, has outstanding "structured knowledge" in that specific field based on their experience and training, understands problems deeply, can accurately and quickly solve problems, and has excellent self-monitoring skills. To develop such a skilled worker, practical on-the-job training (OJT) and so on is carried out, but various problems with this system are evident. Examples include the fact that learning through failure is difficult structurally, there are time restrictions, depending on the circumstances appropriate guidance is not necessarily provided, individuals become satisfied with their level of learning at a certain stage, and thus the knowledge at the site becomes fixed, hindering adaptation to a new environment, *etc.*

Also, although the necessity of knowledge transfer by engineers and skilled operatives in the core manufacturing technology industries has already been pointed out, the sense of crisis in qualitative and quantitative shortages was strengthened with the "year 2007 problem". From 2007, the baby boomer generation, which was responsible for industry during the era of high growth rate in Japan, started to retire in large numbers, raising many concerns. A number of initiatives have been tried to solve the year 2007 problem, but there have been many drawbacks, for example, the skills transfer and know-how took time and did not proceed smoothly; the human resources systems providing guidance were insufficient; and other issues. The main background to these problems is that during the period of high economic growth (the period from roughly 1955 to 1975) new employees were employed in large numbers. Technology and skills were passed down through in-company training. However, after the oil-shock of 1973, energy efficiency, automation, and new technologies were rapidly introduced, and the traditional transfer of knowledge and skills tended to be neglected, which meant that the passing on of technology and skills to the younger generation slowed down. Also, from the economics viewpoint, due to the technology transfer associated with the relocation of factories abroad, mainly to South-East Asia, and with outsourcing, the hollowing-out of technology and skills within Japan has become serious. Following the collapse of the bubble economy in 1991, companies within Japan restructured, and the resultant cutbacks in capable technical and skilled staff, made the transferring of technology and skills even more difficult. Furthermore, as a result of the decline in the birthrate and the dislike for hard, dirty, or dangerous workplaces, it has become difficult to secure young engineers and skilled operatives. This has resulted in a large age gap between the baby boomer generation and the younger generation, so technology and skills are not smoothly passed down. As a result of this situation, measures to pass on technology and skills came into full swing.

At present, transferring skill is typified by technical documents, video libraries, and OJT. Creating technical documents and video libraries requires a lot of labor and cost, and despite their many merits they are not widely used due to poor ease of use. At present, most factories concentrate on OJT for transferring skills.

The problem points with conventional transfer skill methods are as follows. Technical documents are ideal for describing technologies, but they have the disadvantage that it is not possible to describe the movements and skills of operatives very well. Also, video libraries are good at recording and preserving skills, but a lot depends on the knowledge and capability of the person watching the video. Also, in the normal video format it is difficult to immediately watch the part you want to see. In contrast, OJT as shown in Figure 3.1 is an extremely good method of skills transfer, as the whole body can experience the training using a person's five senses of seeing, hearing, taste, smell, and touch. However, this requires much time, and there are problem points; for example, the opportunities for experience are limited by the production of many products in small quantities; and it also very much depends on the educational ability of the person being instructed.

In this way, each of the methods of skills transfer has many advantages, but also has a limit to transfer skills. In addition, looking at these methods from the viewpoint of knowledge conversion, with OJT and video libraries tacit knowledge is transmitted as tacit knowledge, but with technical documents tacit knowledge is converted into explicit knowledge for transmission. Here, explicit knowledge can be defined as "knowledge that can be represented in the language of documents and diagrams, *etc.*" and "knowledge based on objective general laws", and so-called "technology" corresponds to explicit knowledge. On the other hand, tacit

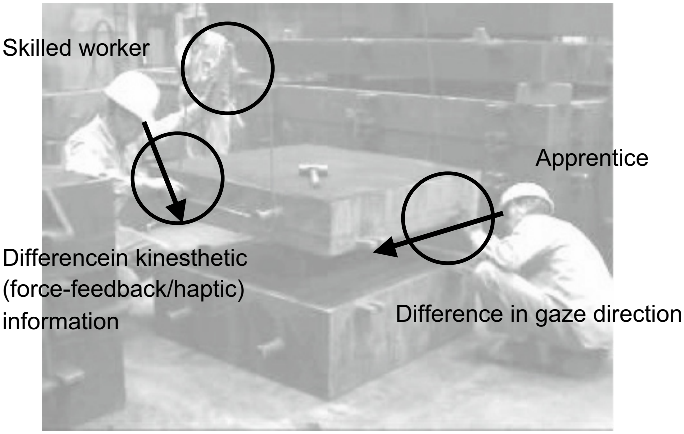

Figure 3.1 Difficulties of OJT

knowledge [4] can be defined as "knowledge that is difficult to represent clearly in the language of documents and diagrams, *etc.*" or "knowledge based on subjective or individual experience", and so-called "skills" correspond to tacit knowledge. Using these methods on their own, where tacit knowledge is transmitted as tacit knowledge or tacit knowledge is converted into explicit knowledge by omitting a part of the tacit knowledge, problems are experienced with the quality, quantity, or efficiency of the transmitted knowledge. In other words, with the main conventional methods of passing down skills, namely technical documents, video libraries, and OJT, effective skills transfer is not possible at present.

3.2.2 New Methods of Skills Transfer

As stated previously, although the conventional methods of skills transfer have many advantages, they also have various problems. Any future new system of skills transfer has the following requirements:

1. It must be possible to easily search for the knowledge that the user requires from amongst the large quantity of knowledge in the system.
2. It must not require a large amount of labor and a high cost for preparation of documents, but must be expandable and flexible enough to be able to re-use documents prepared previously.
3. It must provide a form for easily transmitting tacit knowledge.
4. The quality and quantity of knowledge that can be acquired from images is greatly affected by the knowledge and experience of the individual, so a form must be provided that does not depend on the capacity of the individual. In other words, the large amount of knowledge contained in images must be clearly presented without depending on the capability of the individual.

5. In order that a fictitious, virtual "place (ba)" can be shared, time, spatial, and scale restrictions that interfere with sharing of the "place (ba)" must be overcome at least partially.
6. What is required is not the skills transfer that concentrates on OJT, but an improvement in the quality and efficiency of the knowledge transmitted, using technical documents and video libraries, and so on, and utilizing their respective merits.

3.2.3 Knowledge Creation and Skills Transfer by Sharing of "Ba"

One of the models used for knowledge management is the SECI model (Socialization, Externalization, Combination, Internalization: organizational knowledge creation) advocated by Nonaka and others. This is a model in which knowledge is created by the interaction of tacit knowledge and explicit knowledge through four knowledge conversion processes: (1) socialization; (2) externalization; (3) combination; and (4) internalization [5]. SECI is obtained from the first letter of the four knowledge conversion processes. If these processes are applied to the process of acquiring skills at a foundry, then (1) socialization is the process in which a skilled operative clarifies awareness of problems and recognizes tacit knowledge through OJT or work on site; (2) externalization is the process in which explicit knowledge of casting techniques is acquired from internal documents, technical documents, *etc.*; (3) combination is the process by which a skilled operative generalizes various types of knowledge obtained in the externalization process, and forms their own image of the skill that is to be acquired; and (4) internalization is the process in which the casting skills are made their own by actions and learning based on the created image.

Nonaka and others introduced the concept of "ba" in the field of knowledge management, where ba is defined as a "shared context in which knowledge is created, shared, and utilized" [6]. Context is necessary for the creation of knowledge. The key concept for understanding ba is interaction. Knowledge is not created by the activities of an individual carrying out activities by him- or herself, but by interaction among individuals or interaction between individuals and the environment. Interaction occurs in actual space, virtual space, or a combination of the two. In particular, in socialization and externalization direct face-to-face interaction at the same time and in the same space is important. Ba is the context shared by people that are interacting. Both ba and its participants co-evolve as a result of the self-transcendence and knowledge creation through this interaction.

Itami defines ba as "the framework of circumstances in which people participate, mutually observe whether consciously or unconsciously, communicate, mutually understand, mutually approach, and mutually psychologically stimulate each other" [7]. Further, strictly from the viewpoint of the elements that comprise ba, it is defined as "the framework of circumstances in which a highly dense information interaction is continuously created in various forms through the sharing by more than a certain minimum amount by the participants of a ba of four basic elements that constitute ba, namely agenda (what the information relates to), interpretation code (how the information should be interpreted), information carrier (medium or media conveying the information), and desire for association".

"Ba" can be thought as one of the things to be considered in order to pass down skills. As used here, ba does not just refer to a so-called physical space, as stated previously, but means the space of a specific time, space, or "relationships". In other words, ba is the "interaction relationship". This ba, in other words how this interaction ought to be, may be classified into four types: originating ba, dialoging ba, systematizing ba, and exercising ba. These are defined as follows: (1) originating ba – ba defined by individual and direct interaction; (2) dialoging ba – ba defined by group and direct interaction; (3) systematizing ba – ba defined by group and indirect interaction; (4) exercising ba – ba defined by individual and indirect interaction [8].

In skills transfer, it is extremely important that ba is shared in a specific time and space. Specifically, the case of a highly skilled and experienced operative and a person accompanying the operative at work can be given. By sharing ba in this way, not only can knowledge obtained from the five senses be obtained, but also valuable knowledge of "information that cannot be understood unless in that ba" can be acquired. Hence it can be said that sharing of ba is very beneficial for the skills transfer.

However, the skills transfer by sharing of ba in this way has the following problems:

1. There are time, space, and scale restrictions on the sharing of ba, so there is a limitation making it not possible to efficiently transfer skills.
2. Too much depends on the capacity of the person transferring or receiving the skills, and a large amount of time is required. Under the present circumstances in which skills must be transferred under restrictions of time, cost, and personnel, there are some difficulties aspects of knowledge and skills transfer.

By using an immersion type virtual shared environment system that combines the display of visual information and force information, as described below, it is possible to partially overcome these problems. It is possible to promote the sharing of a fictitious virtual ba, which is considered to be very beneficial for the skills transfer.

One of the work improvement activities in the manufacturing industry is the PDSA/PDCA cycle (PDSA/PDCA cycle: Plan–Do–Study/Check–Act cycle). This PDSA/PDCA cycle is a management method for promoting improvements in production control and quality maintenance, and continuous improvement or work activities in the manufacturing and other industries. This was advocated by W.A. Shewhart and W.E. Deming, who founded quality control in the 1950s, and is also called the Shewhart Cycle or the Deming Cycle (Deming Wheel) [9, 10]. The PDSA/PDCA cycle includes the following four steps: (1) Plan – set a target, and design the process to achieve that target; (2) Do – implement the plan, and measure the results; (3) Study/Check – study and evaluate the measured results, and analyze the results by comparing with the target, *etc.*; (4) Act – identify the points that need to be changed in order to improve the process. These four stages are carried out in succession, and the final "Act" leads to the next PDSA/PDCA cycle, so that work is continuously improved in a spiralling up motion. In this way, continuous and effective knowledge acquisition and implementation by the sharing of ba are necessary for knowledge creation, skills transfer, production control, quality control, and continuous improvement activities in the manufacturing industry. In addition to the conventional skills transfer and work improvement activities, new activities through the sharing of ba and communication are necessary.

3.2.4 Conversation Analysis and Extraction of Knowledge

Ethnomethodology is a theoretical framework for analyzing the process of how people who are active in a real social situation can understand things by talking about those things in a common style and take this understanding to be their reality. Founded by H. Garfinkel, ethnomethodology uses conversation analysis and other methods to focus on the mutual actions between person and person [11]. This conversation analysis is a method that considers everyday conversation and conversation in systematic situations to be a social phenomenon. Social interaction actions have ordered structure and patterns. Also, the participants in the conversation understand the development of the conversation within the sequence of the flow of time. Based on these conversational analyses as the fundamental methodological premise, naturally occurring situations of mutual interaction are recorded by video, and the conversation and the actions are analyzed using the detailed transcript as material [12].

The transcript contains the name of the speaker on the left-hand side of a column, followed by a colon, and the speaker's conversation on the right-hand side. The transcript proceeds as a time series from left to right, and from top to bottom. Four types of symbols are used: for sounds; for the sequence of the conversation; for the transcriber's comments; and for non-verbal actions.

In casting design, the conversation analysis starts from the careful observation of the conversation data, consisting of the sound and visual data and the transcript. The conversation data includes specific actions, conversational procedures, linguistic forms, *etc.* From among these, examples of specific phenomena are collected, and systematically compared and classified. At this time the opinions of several engineers and skilled operatives are obtained, and the collection is analyzed. Based on this data, a knowledge tree is prepared, and it is important that the knowledge is expressed in an intuitive and easy-to-understand manner.

3.2.5 Proficiency and Corporeality

In recent years, research into proficiency has been expanding rapidly. Kitano and others have classified proficient people into skillful proficient people and adaptable proficient people, according to the level of flexibility and adaptability of their knowledge and skills. A skillful proficient person becomes proficient by repeating the same procedure many times, and the speed and accuracy of execution of a skill is outstanding. Also, an adaptable proficient person is a person that has derived conceptual knowledge from executing a procedure, so they can flexibly adapt to the changing circumstances of a task and arrive at an appropriate solution. K.A. Ericsson and others have pointed out that in order to attain proficiency in a skill, well thought out training based on a clear sense of purpose is indispensible [13]. R.R. Burton and others have argued that for learning complex skills, providing a small world in which the complexity gradually increases is effective [14]. A certain skill may consist of several lower level skills, but separating and learning each lower level skill is difficult. However, for this purpose a "small world" is provided for learning appropriate combinations of the lower level skills. By gradually increasing the complexity of these small worlds, the learner is given the opportunity to recognize and correct mistakes that were allowed in the previous small world. By actively monitoring this experience, the formation of still deeper knowledge is enhanced.

Characteristics of a proficient person include learning lower level skills, knowledge acquisition for appropriate problem solving, and the acquisition of appropriate evaluation criteria. Regarding the learning of lower level skills, it is said that in order to reduce the load on the short-term memory, a proficient person makes comparison with long-term memory and remembers by chunking familiar knowledge. There is also research that indicates that by using the knowledge within the long-term memory, the formed chunk does not stay in the short-term memory, but is soon transmitted to the long-term memory, where it can be remembered for a long time. Also, it is said that a proficient person does not carry out controlled processes under conscious control, but carries out automatic processes. Skills are automated as if the person were one with their tools. Next, regarding knowledge acquisition for appropriate problem solving, it goes without saying that a proficient person has mostly structured knowledge, but it is said that this is due to mapping intention and image (*i. e.*, in the internal world) with the corresponding appropriate superficial characteristics (*i. e.*, in the external world). According to H.L. Dreyfus and S.E. Dreyfus, the overall situation in the ba is understood as a pattern by this mapping, which suggests the capability of responding as necessary to confined problems or dispersed problems in accordance with the circumstances [15]. Furthermore, regarding the acquisition of appropriate evaluation criteria, it is thought that a proficient person can respond flexibly to changes in circumstances by constantly monitoring their own state, and by flexibly adjusting their own state.

J.J. Gibson refers to the relationship between the outside world and a person as "affordance", the value and meaning that goes beyond the superficial characteristics and properties of each individual thing or phenomenon. According to Gibson, this is not created in the head of a person, but is already in existence and is directly perceived by that person [16]. Saeki states that a person becoming knowledgeable does not mean that the person possesses knowledge, but that the person becomes more open to the outside world. Saiki states that when an open person encounters the outside world, the prior relationship between the outside world and the person is realized as an interaction. For learning it is necessary that the learner acts in a participating and active manner in order to bring into view a meaningful world [17].

For knowledge and skills transfer, training such as OJT in an actual social setting is of course necessary, as are well thought out training based on a clear sense of purpose, mapping of intention and image with the corresponding superficial characteristics and actions, the learner acting in a participating and active manner, bringing into view a meaningful world, and so on.

3.3 Skills Transfer and Human Resource Development in the Foundry Industry

3.3.1 Knowledge and Skills Transfer of Casting Technology

Kawaguchi City in Saitama Prefecture is one of the major industry clusters of casting related companies in Japan. In the 1960s, there were almost 600 foundries in Kawaguchi, which employed 12,000 people producing 400,000 tons per year. At present, Kawaguchi is a forest of high-rise apartments and office buildings, having been greatly transformed by the effect of the three factory acts. However, there are still over 100 foundries in the area that make use of advanced casting technology and skills to produce high-added-value cast products to support the foundations of Japan's advanced technology industry.

A cast product is normally produced through a sequence of processes. In particular, the work at the foundry site, such as melting, molding, mold assembly, pouring, and shake-out, requires not only casting knowledge, but also sensitivity to weight, a sense of touch, sound, smell, color, temperature, and so on, so skills that make use of all five senses are required. Much of the work at a foundry requires experience and intuition, including ramming, coating, mold assembly, and pouring, and the existence of this tacit knowledge is one of the factors that makes the acquisition of skills difficult.

In order to transfer these casting technologies and skills as well as create still higher added-value products, efforts directed towards the skills transfer and knowledge creation are necessary. For this purpose most companies have activities in place for skills transfer which are centered around technical documents, video libraries, and OJT, as mentioned above. However, the present situation is that effective transfer of advanced skills is not possible by the simple use of these methods. Therefore, a new system for advanced skills transfer is necessary.

3.3.2 New System for Skills Transfer

In the casting process, besides explicit knowledge of the technology for making castings, tacit knowledge in the form of skills is necessary. In order to design and manufacture high-added-value products, it is necessary to obtain knowledge that skillfully combines this explicit knowledge and tacit knowledge, as well as master technologies and skills through OJT or the like.

In our study, we consider an example of the utilization of a skills transfer system and an immersive virtual environment system and their correspondence with the knowledge conversion processes of the SECI model. Here, (1) socialization is the process in which a user clarifies awareness of problems and becomes aware of tacit knowledge through OJT and work on site; (2) externalization is the process in which the user acquires explicit knowledge from documents, technical data, *etc.*, using the skills transfer system; (3) combination is the process in which the user acquires knowledge from images, *etc.*, presented in the form of a combination of explicit knowledge and tacit knowledge; and (4) internalization is the process in which the user makes the actions and learning their own, based on the knowledge obtained from the skills transfer system. When making knowledge one's own while using the skills transfer system in the externalization and combination processes and using the immersion type virtual shared environment system in the internalization process, acquisition of new tacit knowledge as well as the creation of new knowledge is possible.

The authors have developed a skills transfer system for efficient and effective knowledge acquisition using multimedia and VR technology in each of the knowledge conversion processes of the SECI model. This is an example where the utilization of the skills transfer system and the system using the VR technology correspond to the knowledge conversion processes of the model. Here, externalization may be substituted for the process in which a user obtains explicit knowledge from documents and technical data, *etc.*, using a multimedia skills transfer system; combination may be substituted for the process in which the user acquires knowledge presented in the form of a combination of explicit knowledge and tacit knowledge; and internalization may be substituted for the process in which the user makes the acquired skills their own by mock experience within the VR space, based on the knowledge obtained from the skills transfer system. It is when making knowledge one's own while using the skills transfer system in the externalization and combination processes, and using the VR space in the internalization process, that the creation of new knowledge is possible

3.3.3 Skills Transfer System Using Multimedia Technology

Figure 3.2 shows an outline of the skills transfer system. By searching for and visualizing the knowledge, a user can efficiently access the required knowledge.

Tacit knowledge is presented using Synchronized Multimedia Integration Language (SMIL), and explicit knowledge is presented using eXtensible Markup Language (XML). Links are provided to the knowledge associated with keywords, so when necessary the associated information and knowledge can be efficiently acquired. Also, parts that cannot be expressed in images are complemented with links to three-dimensional CAD data and CAE simulations. It is expected that the use of this system will have a large effect that cannot be obtained through conventional skills transfer through sharing of a ba or skills transfer using video libraries, *etc.*

The system assumes the use of a web-based system, and therefore uses languages suitable for use on the web, such as XML, SMIL, and XVL (eXtensible Virtual world description Language). To use the system, the user first searches or navigates through the system, and the target knowledge is accessed from the list of search results or by following the navigation. In the case of knowledge classified as tacit, a multimedia screen using SMIL is presented; in the case of knowledge classified as explicit, documents are presented using XML. Links are provided to knowledge as keywords, and when necessary a user can select a link to receive only the knowledge that is required. Also, for parts that cannot be explained solely using images, and parts that cannot be explained solely using documents, documents and images are mutually linked so that their respective advantages can be utilized. Also, parts that cannot be explained using static or two-dimensional images are supplemented with images that can be easily controlled by the person watching, using three-dimensional CAD data or CAE simulations.

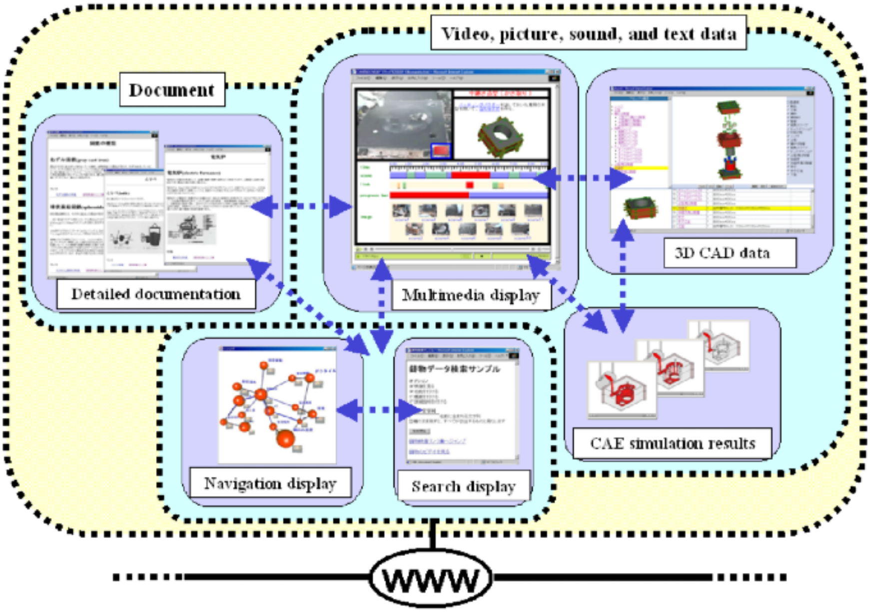

Figure 3.2 Knowledge transfer system

As described above, by linking tacit knowledge with explicit knowledge, tacit knowledge can be presented to a user in a form in which the knowledge is easily transmitted. Also, the required knowledge can be easily searched for, so the user can select the required information as necessary and learn it, so knowledge can be efficiently acquired.

3.3.4 Casting Skills Acquisition System Using VR Space

As shown in Figure 3.3, in the skills transfer system, (1) after acquisition of the explicit knowledge, (2) the explicit knowledge is linked with tacit knowledge. Then (3) using the skills training system based on VR technology, the knowledge obtained in the skills transfer system is internalized and corporeal knowledge is acquired. Finally, (4) through OJT on site the high-level skills are confirmed, and the new skills are acquired. By repeating this series of processes the skills are further developed, and new knowledge or higher level skills are acquired. Here the skills virtual training system using VR technology is called CAMRobot (Cyber Assist Meister Robot). This virtual training system combines a touch panel type computer, a three-dimensional visualization device, and a force sensing device, and supports education in design and manufacturing knowledge and knowledge creation for new high-added-value products. Using this system new people and people with insufficient accumulated experience can obtain experience that is

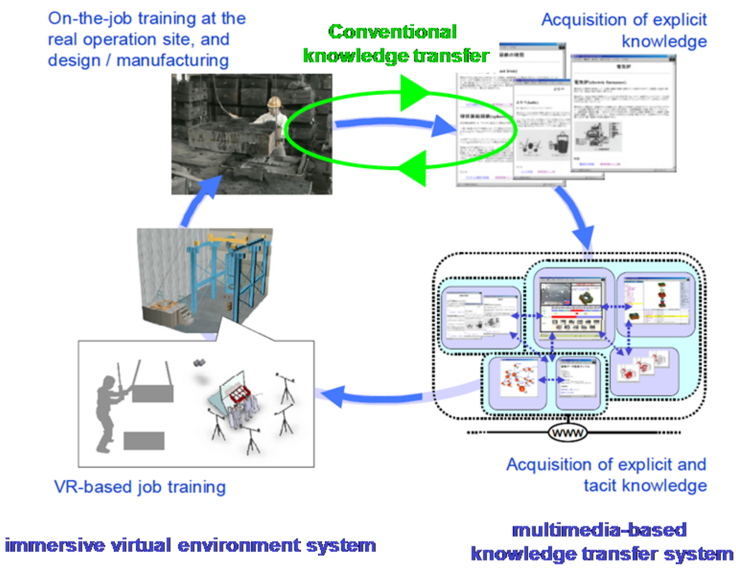

Figure 3.3 Process of knowledge acquisition and human resource development

close to repetitive on-site work. In this chapter, the annotation input and display system that can be used with the skills training system virtual training system is described. In this way annotation or similar can be shown in the space on a model displayed in the VR space, which promotes sharing of technical information, communication between engineer and skilled operative, and enables the acquisition of corporeal knowledge.

Figure 3.4 shows an outline of the immersive virtual environment system. This VR system combines a three-dimensional visualization device and a force feedback device, so a user can experience the hardness and weight of three-dimensional objects. By experiencing images displayed within the virtual environment, not only visually, but also by touch and by sensing force, the internalization of casting knowledge is promoted. The display of three-dimensional shapes in the three-dimensional visualization device and input control to the force feedback device are carried out in an integrated manner by a PC, so the three-dimensional images and the force sensing are synchronized. The position of the field of vision is fed back to the PC by a head tracking device fitted to the three-dimensional visualization glasses, and images are displayed in real time in accordance with the position of the field of vision. In the force feedback device, the position of the tip of the manipulator and the load on the manipulator are fed back to the PC, and the position and force of the manipulator are appropriately controlled taking into consideration the displayed three-dimensional shape. It is considered that by using this system to provide a visual and force sensing ba for the acquisition of skills, it is possible to partially overcome the problems associated with the acquisition of casting skills.

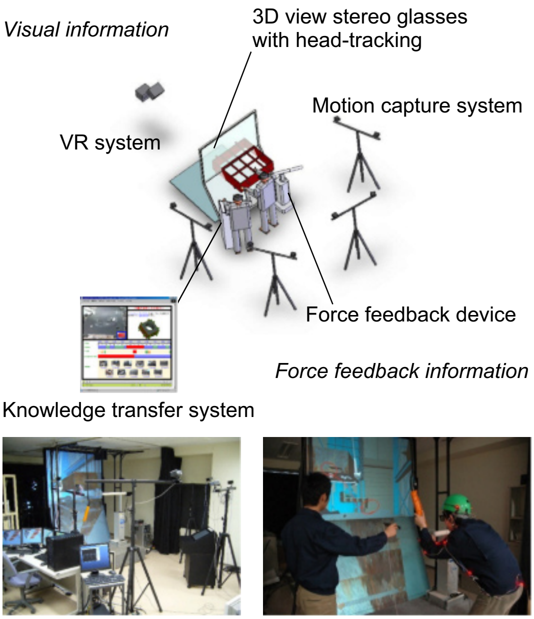

Figure 3.4 Immersive virtual environmental system

In the ramming process, foundry sand is rammed with a rammer while pouring the foundry sand into a metal form, so that the sand is evenly spread throughout. The knowledge to be acquired for this process is not only visual, but also the sensation of ramming with the rammer is important. The foundry sand frequently used today starts to harden soon after it is poured into the metal form because it contains hardening resin, so the operation must be quickly completed. Unskilled persons learn this work through OJT on site, but failure is normally not acceptable in product manufacture, so the opportunities for an inexperienced person to learn are limited. When the VR system is used, the sensation of the ramming process is provided by the three-dimensional visualization device and the force feedback device. Also, because a real product is not being manufactured, it is possible to repeat this experience any number of times. Also, by measuring in advance the work data of an experienced skilled person, this data can be taught using the force feedback device, so it is possible to directly experience the details of the work of a skilled person. By learning not just the visual information, but also data associated with the sensation of the force applied by the rammer in the ramming operation, it is possible to directly acquire tacit knowledge.

3.3.5 Skills Transfer and Human Resources Development Through Emotional Interaction in VR Space

Our proposed system is the framework for skills transfer and knowledge creation through communication between engineers and operatives in VR environment and the skills transfer system in accordance with this framework. A system has been developed which enables explicit knowledge from technical documents, *etc.*, to be efficiently acquired using multimedia, and tacit knowledge such as skills to be acquired through visual and force sensing experience of actual work on site using a combination of the three-dimensional visualization system using VR technology and force feedback device utilizing robotic technology. It is important to experience these with communication between several operatives mixed in. Our system is displayed on projection VR systems, which allow many people to simultaneously share the experience. Interaction between all the viewers present is generally very high. Most trainees in this experience are influenced by the experience, and immediately begin sharing their feelings with the others in this group. Also, most trainees can acquire tacit knowledge, embodied ***knowledge,*** and skills by sensory-motor and implicit emotional learning memory. An emotion is a mental and physiological state associated with a wide variety of feelings, thoughts, and behavior. This is based on the Latin *emovere*, where *e-* (variant of *ex-*) means "out" and *movere* means "move". So, it is easy to acquire the skills transfer and human resources development through emotional interaction in VR space. In VR space an environment is created in which several engineers and operatives can participate, and while communicating cooperatively acquire design and manufacturing knowledge. In other words, a virtual environment is created in which effective OJT can be carried out with highly experienced skilled operatives. By doing this before the actual OJT, the skills transfer and human resources development can be carried out more effectively over a shorter time period.

3.3.6 Skills Transfer with an Annotation Display System

Figure 3.5 shows the structure of the annotation display system. The principle of this system is that a magnetic three-dimensional position sensor contained on the tip of the annotation display device carries out the writing operation, and in addition acquires positional information. At the same time the model for annotation is displayed within the VR space. By turning the display device switch on or off, it is possible to show text or graphics.

This annotation display system was applied to the mold assembly work. Tests were carried out on mold assembly work using VR with ten pairs of people, each pairing consisting of an experienced person (instructor) and an inexperienced person (operative). A questionnaire survey was carried out with the instructors regarding the ease of communication with and without the annotation display, and a questionnaire survey was carried out with the operatives regarding the ease of understanding with and without the annotation display. When the explanation times with and without annotation display are compared, no difference in explanation time was found. This is considered to be because the annotation display system did not take so much time to operate; it was easier to explain using a combination of words and annotation display than by words alone. For work training, explanation using words alone is difficult, and for pointing out a particular place or the like, it is considered to be more effective for the instructor to use the annotation display system. Also, from the results of the questionnaire regarding the ease

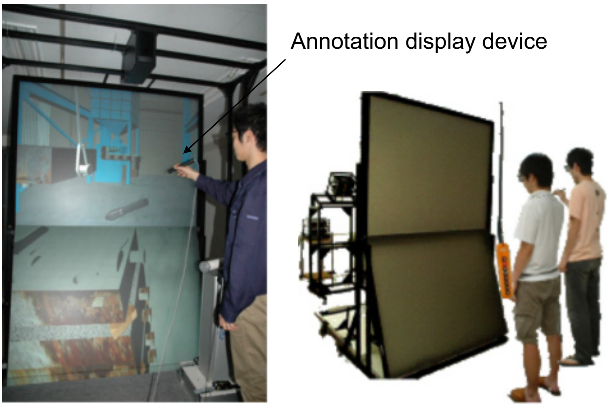

Figure 3.5 Skills transfer with an annotation display system

of communication with and without the annotation display system, all persons replied that explanation was easier using the system, demonstrating that the annotation display system is effective for communication.

3.3.7 Work Training by OJT and Sharing a Ba in a Virtual Training System

A new motion capture system was introduced into the virtual training system, and the new virtual training system for analyzing the bodily movements of the operative and analyzing the work are performed. In this system a high-accuracy motion capture system is added to virtual training system. The motion capture system has a resolution of 3600×3600 pixels, 480 Hz high-speed sampling, and LEDs each with their own ID, *etc.* It is capable of recording the motion history of the operative with high speed and high accuracy. Using our system and near-infrared spectroscopy, it is possible to study in detail the work motions and brain activities of skilled workers as shown in Figure 3.6.

Using the motion capture system, the motion histories and coordinating motions of operatives were recorded and studied. LEDs were fitted on various parts of the body of the operative, and the trajectory of each part was recorded. In the figure, one point each for the trajectory of the head, left hand, and right hand only are shown. Differences in the motion history of different operatives were observed. By determining the differences in motions of the operatives not only qualitatively, but also quantitatively, it is considered that in work training using VR it is possible to study the degree of proficiency of work or clearly see the differences from the work of a skilled operative in VR space.

We studied the results of a study of differences in the training effect for mold assembly training in VR space when visual information and force feedback information are linked, for the case of visual information only. Eight subjects whose knowledge of casting was poor carried out an operation to assemble a top mold on a bottom mold by operating the buttons on the crane operation panel in VR space. The time taken from start of assembly to completion and the positional error between the top mold and the bottom mold when the assembly was completed were measured. The positional error was found when the dowel in the top mold was placed into the dowel hole of the bottom mold when the eight subjects were provided with visual information only. Also, the positional errors using visual information and force feedback information were compared. It can be seen that the positioning accuracy is improved when force feedback information is provided compared with the case when using visual information only. We also studied the average number of times during the operation that the mold touched the core or dowel. In actual work, if the core or dowel is damaged, it is necessary to repair the damage, but here even in the case of contact, the work can be carried on to the end. As a result, it can be seen that for most subjects, the number of contacts with the dowel or core was less than when visual information was linked with the force feedback in-

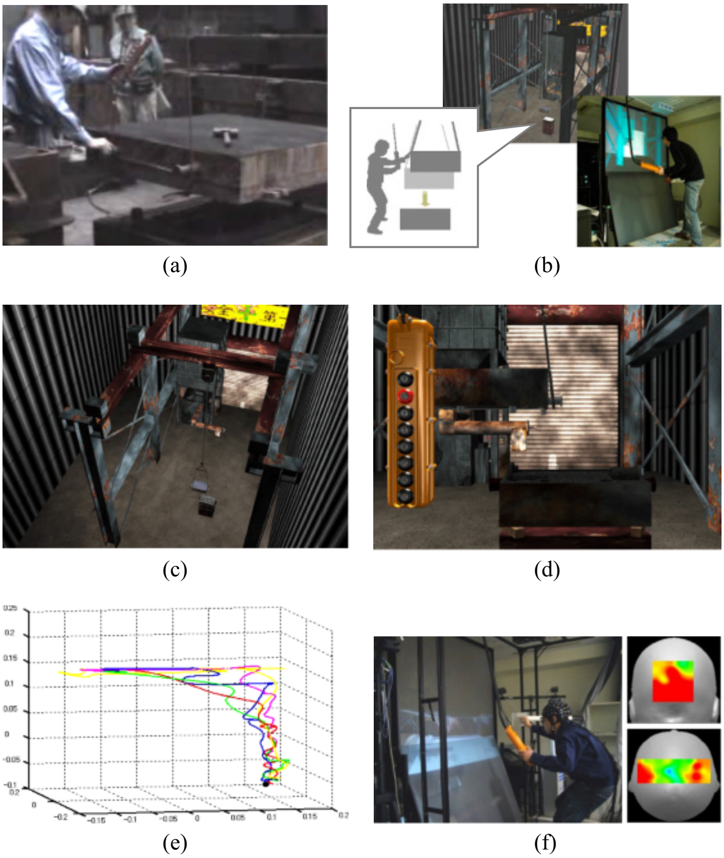

Figure 3.6 Mold assembly: (a) actual operation, (b) virtual operation, (c) and (d) virtual foundry, (e) result of virtual training, and (f) brain activity measurement

formation. The average amount of time required for each subject to complete the work was calculated. It can be seen that for all subjects, the operation time was shorter when visual information was linked with force feedback information.

The following is a description of the differences between work training by OJT and by the virtual training system. In work training using the VR system with high-accuracy motion capture, there were a number of differences compared with when using OJT on site. By using the two systems the operative and the skilled person can share a ba at a remote location, and work training can be carried out between the skilled person and the operative at the remote location. In this case, by capturing the motions of the work of the skilled person and displaying them superimposed on the same positions of the operative, the operative can stand in the viewpoint of the skilled person, and can trace the work motions. Compared with watching from a different viewpoint and then copying on site, more efficient work training is possible. Also, the display of annotation within the space, and display of associated information, images, *etc.*, within the space is possible, unlike in the real space. Therefore, in combination with motion capture, by displaying with an arrow the direction of movement of the arm or foot during work training, and displaying the amount of force applied using numerical information or image information, it is expected that work training can be made still more efficient.

3.4 Augmented Reality-based Training System

3.4.1 Augmented Reality

Augmented reality (AR) is the overlay of computer graphics onto the real world and has many potential applications in industrial and academic research [18]. One of the most difficult parts of developing an AR application is precisely calculating the location of the camera in real time so that the virtual image is exactly aligned with real world objects. The ARToolKit allows this to be done easily. The AR-ToolKit tracking works as shown in Figure 3.7.

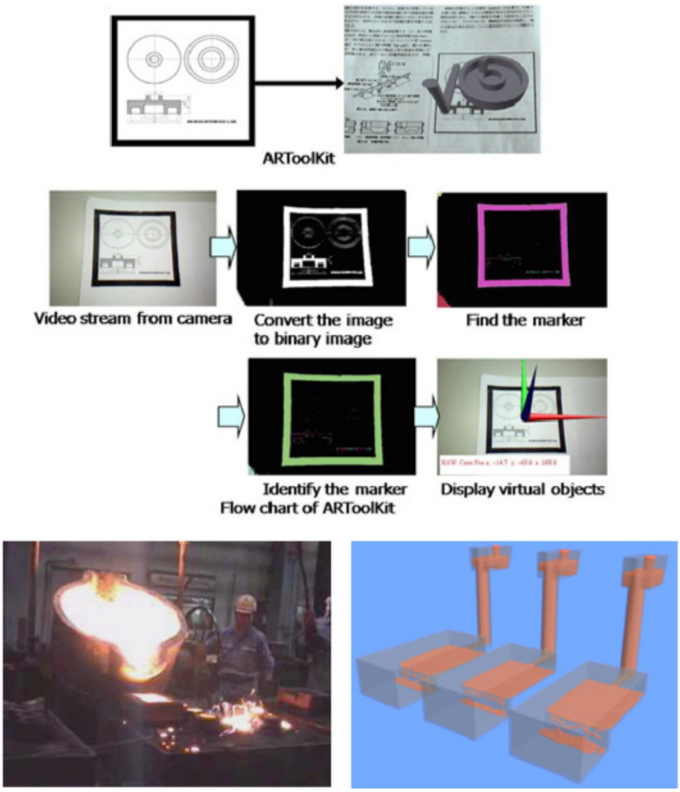

Figure 3.7 AR-based training system

ARToolKit is a software library for building AR applications. The ARToolKit video tracking libraries calculate the real camera position and orientation relative to physical markers in real time, enabling the development of a wide range of AR applications. Some of the features of the ARToolKit include single-camera position/orientation tracking, tracking code that uses simple black squares, the ability to use any square marker pattern, simple camera calibration code and sufficient speed for real-time AR applications. ARToolKit is a C/C++ language software library that allows programmers to easily develop AR applications. ARToolKit uses computer vision techniques to calculate the real camera position and orientation relative to marked cards, allowing the programmer to overlay virtual objects onto these cards. The fast precise tracking provided by ARToolKit is expected to enable the rapid development of many new and interesting AR applications.

3.4.2 Training System for Pouring

Casting is an operation whereby metal is shaped by pouring it in a liquid state into a mold, followed by solidification. Casting is also a method of detailing the metal as a result of pouring it into a mold.

Fluidity is the ability of metals to flow through a gating system to fill the cavity of a casting mold and conform to the shape of the mold. Fluidity is determined by the solidification interval, viscosity, and surface tension. Metal is cooled by heat transfer upon contact with the mold and the viscosity consequently increases. The metal solidifies upon further cooling, resulting in a misrun. To avoid misrun, engineers must pour the metal quickly. However, since the mold is made from sand, pouring too quickly can cause breakage or distort the shape of the mold. Therefore, it is critical to pour the metal at an appropriate rate. Engineers must consider both the shape of the mold and the metal's fluidity to determine the proper rate of pouring. However, this is a difficult task, especially for beginners. Therefore, engineers must be trained to pour metal properly in addition to studying its fluidity.

Figure 3.7 shows the AR-based training system for pouring. We built the system using the ARToolKit. The system displays fluidity that is simulated by simple physical models in real time.

The ARToolKit tracking works as follows. (1) The camera captures video of the real world and sends it to the computer. (2) The software on the computer searches through each video frame for any square shapes. (3) If a square is found, the software calculates the position of the camera relative to the black square. (4) Once the position of the camera is known, a computer graphics model is drawn in the same position. Thus, users can see virtual objects from every angle by moving a camera. In the proposed system, we display a mold and ladle on the marker and users operate a keyboard to rotate the ladle and pour metal.

The proposed system displays the fluidity in the mold for training purposes. It is important to display fluidity in real time, while considerable detail is not necessary, since the system is not for fluid analysis. The proposed system can also display the results of the fluid analysis that is preliminarily calculated in considerable detail if requested by the users. The proposed simulation, which uses simple physical laws, is considered to be useful for training.

3.5 Work Support for Elderly or Female Workers

Here, new experiments in lifestyle support for the elderly and work support for workers, *etc.*, using VR technology are described.

3.5.1 Aging Society and Labor Problems

The total population of Japan as of October 1, 2004 was 127.69 million, with 24.88 million people aged 65 years or older, or 19.5% of the total population. The elderly population will increase rapidly up to 2020, and in conjunction with the reduction in total population the percentage of elderly is predicted to reach 26.0% in 2015, and 35.7% in 2050. The working population aged 65 years or older in 2004 was 4.9 million, or 7.4% of the total population.

Currently in Japan, a wide range of measures for the aging society, such as measures for employment and income, health and welfare, learning and social participation, lifestyle environment, and survey research, are being taken, and the number is steadily increasing. In order to further maintain and expand the vitality of Japan, it is important to achieve a society in which everyone from young people to old people, in particular those responsible for the aging society, can use their capability and experience, not only at home but also to be active in society.

In the “Questionnaire survey of the promotion of participation of the elderly in society” prepared by the Japanese government, it was pointed out that it is necessary to create a system in which all workers, including the elderly, can work in accordance with their willingness and capability. It is necessary for problems such as wages and conditions, forms of work, retirement system, and so on, to be solved, and there is a strong need to support improvements in worker education and working capability.

For work support, it is very important to share a ba in a specific time and space. Specifically, it is important to carry out work with an instructor in an actual workplace. By sharing a ba in this way, not only can knowledge acquired through the five senses be obtained, but also valuable “information not obtainable unless in that ba” and corporeal knowledge can be obtained. Sharing a ba in this way can be said to be very beneficial for work support. Work support by sharing a ba in such a way places a large burden on the aptitude of the personnel carrying out the work guidance, and a lot of time is required. This has the problem that it is difficult to carry out work support under the present circumstances in which there are time, spatial, and financial restrictions.

Using VR technology in which visual information is combined with force feedback information, and where both are provided at the same time, these problems can be partially overcome. It is possible to promote the sharing of a mock virtual ba, and communication from person to person can be exchanged, so it is considered that this is very beneficial for work support.

3.5.2 Work Support for the Work of the Elderly or Female Workers

Based on the rapid spread of the effect of the low birth rate and aging in society, in June 2004 the law concerning stabilization of employment of elderly persons was partially revised with the aim of creating an employment environment in which the knowledge and experience of the elderly can be utilized. Also, female workers play a large role in the development of the economic society, and it is important in the future to provide an environment in which female workers can use their full capability. By using the VR system as described, it is possible to create a work environment that takes into account elderly and female workers, and use it for work training in that environment. Assuming various work environments and work contents, as shown in Figure 3.8, a work environment suitable for all workers, including the elderly and females, can be studied while providing mock experience within the environment, and work training can be supported.

Figure 3.8 Work support considering universal design

3.5.3 Construction of a Teleworking Environment as a Work Form with Variety

In recent years, attention has been focusing on teleworking (work at home, work at satellite offices, *etc.*) as a flexible form of work, unconstrained by place and time. For workers that need to care for the elderly, for children, or other nursing care, teleworking is a useful form of work that reduces the burden of commuting, and has few bodily or time restrictions. In the past, telework was mainly applicable only to programmers or desk workers, but by using a fusion of the three-dimensional visualization device, force and touch sensing, and the display device developed by the authors, the manufacture of shaped products, product development, and other creative work based on visual information and force and touch sensing information is becoming possible.

3.6 Conclusions

This chapter has described a new VR/AR-based skills transfer and human resources training taking casting as an example where high-level skills are required. Also, new experiments in work support for the elderly and females using VR technology have been described. In order to efficiently and reliably internalize work in manufacturing workplaces, effective skills transfer and human resources development can be carried out not just by knowledge alone, but by adding visual information, force feedback information, and emotional communication.

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