Computer-aided support system for metal diagnosis of patrimonial objects

Antoine Rosselet[1], Marcel Grosjean[1], Christian Degrigny[2] and Cédric Gaspoz[1]

[1]Information Systems and Management Institute, HES-SO // University of Applied Sciences Western Switzerland, HEG Arc, Neuchâtel, Switzerland
{antoine.rosselet, marcel.grosjean, cedric.gaspoz}@he-arc.ch

[2]Haute École Arc Conservation-restauration, HES-SO // University of Applied Sciences Western Switzerland, HE-Arc CR, Neuchâtel, Switzerland
christian.degrigny@he-arc.ch

Abstract. Metal diagnosis of heritage objects is a difficult task performed by conservators, mainly due to the fact that invasive techniques are not allowed on these artifacts. Therefore, conservators have developed diagnosis methods based on the observation of the corrosion forms of the objects. However, although these methods are useful to share a common representation of one specific object, they are very difficult to use to compare or search for objects presenting similar corrosion forms. To support the comparison of different objects, we propose a new support system built upon these methods. This paper presents an innovative way to use C-K theory in order to build an artifact in an interdisciplinary context. The resulting artifact integrates concepts and knowledge borrowed from both the conservation-restoration and the information systems fields.

Keywords: Decision support, design theory, interdisciplinary research.

1 Introduction

Besides advanced technical skills, the treatment of ancient heritage metal artifacts requires a univocal identification of the metal composing the artifacts. Due to their unique nature, any analysis must be carried out in a non-invasive way. This implies that no physical sampling can be performed on them for diagnosis purposes. Bertholon [1] developed a new methodology to standardize the description of corrosion forms observed macroscopically or in detail using a microscope. They are represented as stratigraphies comprising multiple strata, each representing a specific layer of the corrosion forms. Such graphical descriptions can be used by conservators to locate the limit of the original surface. Furthermore, active corrosion layers might be identified within the stratigraphy. Therefore, this methodology can orientate the conservation treatment to be employed [2].

Currently, there is no known support tool to assist conservators in using this methodology to perform non-invasive diagnosis of ancient metal artifacts. Due to the pencil/paper nature of the method, it is extremely difficult to find similar

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stratigraphies across publications or databases. In order to support the broader diffusion of the method, its initiators are looking for a tool to assist conservators during the identification process of the metals composing the artifacts [3]. To support the design process of an integrated decision support system (DSS) aimed at supporting non-invasive diagnosis on ancient heritage metal artifacts, we decided to use the C-K theory framework. "C-K theory bears upon existing design theories, yet it re-interprets these theories as special cases of a unified model of reasoning" [4]. C-K theory integrates creative thinking and innovation in its core, giving space for the emergence of something unknown from what is known. Thus, in the context of interdisciplinary research characterized by our topic and defined as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline, and draws on the disciplines with the goal of integrating their insights to construct a more comprehensive understanding" [5], C-K theory will support the emergence of a more comprehensive solution of the problem, relying on the distinction of the spaces of "Concepts" (C) and "Knowledge" (K) from multiple fields [4].

Borrowing concepts and knowledge from information systems (IS) and conservation-restoration (CR) fields, we were able to design a new tool aimed at supporting the non-invasive diagnosis of heritage metal artifacts. In the first part of this paper, we briefly present C-K theory and the issues raised by the current application of Bertholon's methodology [1] in the context of the diagnosis of heritage metal artifacts. In the second part, we present the design process of an integrated decision support system aimed at supporting the stratigraphic methodology during the diagnosis process of heritage artifacts. In the third part, we discuss how C-K theory was able to support the process and, moreover, how we were able to create new knowledge (K) from the process itself.

2 C-K Theory in an Interdisciplinary Research Context

C-K theory was invented and has been developed by Hatchuel and Weil [6] since the early 2000s. The authors proposed what is called a unified design theory. Its name is composed of the first letter of "Concepts" and "Knowledge", as it is built around the distinction between and yet the complementarity of these two components. Indeed, it is based on the idea that the dynamics of design can be modeled "as a joint-expansion of a space of concepts (C-space) and a space of knowledge (K-space)" [4].

On the one hand, K is a "knowledge space, the space of propositions that have a logical status for a designer D" [4]. The idea of a logical status of a proposition is "an attribute that defines the degree of confidence that D assigns to a proposition" [4]. On the other hand, a concept is "a proposition, or a group of propositions that have no logical status in K" [4]. This means that "when a concept is formulated it is impossible to prove that it is a proposition of K" [4].

Given the interdisciplinary nature of this research, C-K will support bridging the concepts and knowledge from two independent fields in order to build a unified response to an interdisciplinary problem.

2.1 C-K Theory in Practice

C-K theory breaks down a general concept into smaller parts, each of which relies on knowledge or activates knowledge. At the end of the process, a design is found when new knowledge is generated from a concept, i.e. when a concept can be validated. During the design process, concepts can be validated. However, as long as they do not represent a satisfactory design, they are expanded further. Thus, both the concept and the knowledge spaces need to expand to lead up to a feasible solution. This expansion takes numerous forms, because it can in both cases come from C or K. In C-K theory, there are four operators that fall into two categories: external and internal. The following table sums up the different expansion cases (Table 1):

Table 1. The four operators in C-K theory

–>	C	K
C	Internal	external – conjunction
K	external – disjunction	internal

From C to K (C → K): this is a concept that gets validated by an expert, an experimental plan, a prototype, etc. This operator comes from C and expands the available knowledge in K [4].

From K to C (K → C): this illustrates a knowledge that is transformed into a concept. It generates alternatives in the C-space that come from the knowledge space [4].

From C to C (C → C): starting from a concept, the C-space is expanded by partitioning it. The C-space is tree-structured, as several expansions are generated from a single concept [4].

From K to K (K → K): this is an expansion of the K-space that comes from other knowledge. For instance, proving new theorems constitutes such an expansion, as they mobilize existing knowledge [4]. The required knowledge can then lead to K → C operators and an expansion of the C-space.

The modeling of C-K theory starts with a disjunction, which generates a first concept that constitutes the basis for the expansion of both the C- and K-spaces. It ends when a satisfactory conjunction is found, when a product or a solution that is recognized to be feasible is created from a concept [4].

In the case of an interdisciplinary research, where design needs to emerge from knowledge of several fields of study, the C-K theory proves to be particularly useful. In a project-based study called “Design and Application of Intelligent Electronic Systems” [7], a feasible design was found using the C-K theory and an interdisciplinary approach. Engineering and design students attended the same course and then were asked to create an object that embedded an electronic system, each group borrowing knowledge from its own field of study and from the course they attended. The study concluded that collaboration between engineering and design students through brainstorming – which created disjunctions and conjunctions by activating knowledge – helped to design an object that met the initial requirements. Moreover, the use of C-K theory showed how new concepts were generated by simultaneously applying knowledge from the design and the engineer fields, while expanding the K-space.

Along with the development of the C-K theory, Hatchuel [6] also introduced the idea of "K-relativity". He declares that "a specialist may see a fantastic innovation in something where we see nothing new, as the expansion is invisible to us. Our ability to recognize an expansion can depend on our sensitivity, our training or the knowledge at our disposal" [6]. Collective design and K-relativity are both embedded in an interdisciplinary context, as designers have other knowledge or different interpretation of a given knowledge. This interpretation will depend on their respective field of study. Chou [7] deals with this issue by adding tags to concepts and knowledge in his use of the C-K theory. Thus, in his case, concepts and knowledge can either be formulated by engineering students, design students, or both. This led to new and technique-proven designs.

2.2 Interdisciplinary Research Supporting the Non-invasive Diagnosis of Heritage Artifacts

In order to design a tool which is usable and which constitutes an added value for the conservators, researchers in CR and in IS have to collaborate closely with each other. Indeed, it is from an interdisciplinary context and a gathering of knowledge that a first solution has been found. Building on this complementarity, actionable data structures have been designed. They constitute the first step for further development and refinements [3].

If each department had worked alone, limits would have been reached rapidly. As far as the CR department is concerned, they use a methodology developed by Bertholon [1] that allows them to model stratigraphies using his framework and nomenclature. Using a pencil/paper method and/or Adobe Illustrator [8], they are able to represent the stratigraphies. Then they can make visual comparisons between different artifact structures. However, they cannot go any further by themselves, as they would need knowledge from the IS field to implement automatic comparison and matching of stratigraphies under construction with those in a database.

With regards to the IS department, we also noticed that techniques borrowed exclusively from the IS field (e.g. image recognition) could not address the issues raised by the conservators in a satisfactory way [3]. Indeed, the tool needs to take the business-specific aspects of CR and their methods into account, as the end users are the conservators, who are used to working with their own methodology.

Thus, in the final step of DSS conception, we merge the knowledge that comes from both of these fields (CR and IS) to expand the C- and the K-spaces. We can therefore achieve our goal and design an appropriate tool to be used by the conservators.

3 C-K Supported Design Process of a DSS

In our use of the C-K theory, the starting concept emerged from the CR department. They wanted a tool that could help them compare a corrosion form of an artifact under investigation with those of a database. Then we used C-K theory to break it down using C → C and K → C. This framework helped us find a feasible solution that met their requirements.

As far as the K-space is concerned, we focused our research on decision support systems (DSS), as the knowledge we have in this field was useful for fulfilling the needs of the researchers in CR [3]. This notion of DSS will play an important role in the expansion of the K-space (K → K) in our process and in the design of the new tool. That is why DSS constitutes the primary knowledge in our framework.

We can then decompose the first concept into two categories: support of invasive and non-invasive analysis. The first one would be to support sampling techniques used on ancient artifacts. This triggers a C → K conjunction which mobilizes the knowledge the conservators have about such methods which are used on non-heritage artifacts. However, the professional ethics prevent the researchers from applying such techniques to heritage artifacts which are meant to be restored, as these techniques can permanently damage the object. Therefore, our tool will need to support non-invasive analysis. This implies a visual observation of the artifact in the first place and a disjunction (K → C) (Fig. 1).

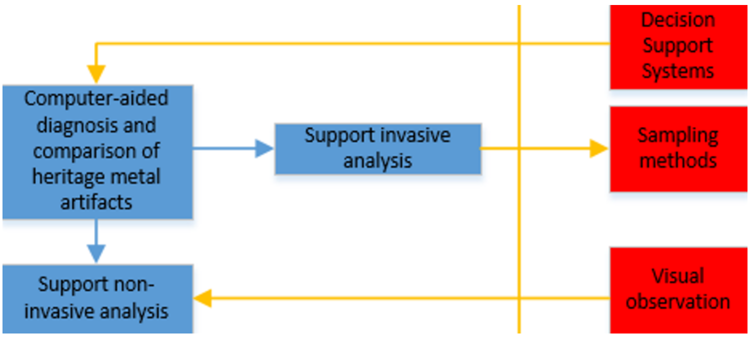

Fig. 1. Starting concepts, knowledge and their links in the C-space (left) and the K-space (right)

Further refinements of the concept of supporting non-invasive analysis based on visual observation leads to a new decomposition between human analysis and computer-automated analysis. As far as the latter is concerned, we thought about the possibility of mobilizing the knowledge we have about image recognition. If we followed this path, a tool that would support such a method could be implemented. Therefore, the knowledge which results from this conjunction constitutes a possible solution. However, we wanted to enquire more deeply about other potential developments, as we are only at the beginning of the C-space decomposition. In addition, we did not have the necessary technology to implement a solution based on image recognition. That would have also meant that most of the process would have been automated, and this is not what the conservators wanted.

Unlike computer-automated analysis, human analysis is based on the use of a binocular microscope in order to capture more information about the corrosion forms of the object. Using binocular vision could also be deduced from the knowledge about visual observation, as it represents a more accurate tool to perform non-invasive diagnosis (Fig. 2). Hence, we can notice that a knowledge can simultaneously emerge from a conjunction and an internal expansion of the K-space, as suggested by Hatchuel [9] in an illustration of the C-K theory.

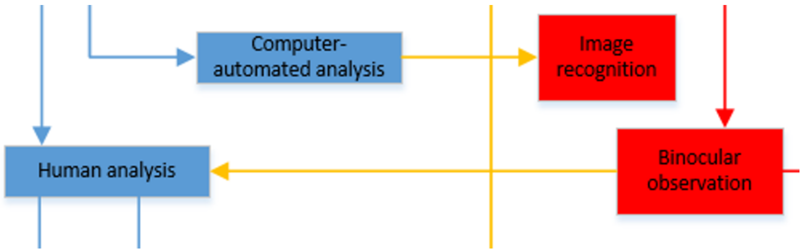

Fig. 2. The concept of a support for non-invasive analysis can be broken down into computer-automated and human analysis

Concerning the K-space, new knowledge is activated from the use of binocular vision to perform relevant diagnosis. Indeed, a closer look on the metal artifacts which are analyzed by the conservators shows that they are corroded and therefore composed of layers which can be more or less distinguishable, depending on the artifact. The knowledge about the layers which form the structure of the artifact is well established for the conservators. Indeed, as we saw previously, Bertholon [1] has developed a stratigraphy model that is used by conservation professionals to categorize the different layers according to their families and comprehend the ongoing corrosion processes.

This is a critical knowledge as the conservators want to standardize their analysis around this method. Consequently, human analysis can further be broken down into two other concepts: a representation of the artifact layers based on the model developed by Bertholon or a simple drawing of the layers. The drawing could be performed either by hand on paper or with the help of a computer drawing software [8] (Fig. 3), which allows the user to draw what he sees without following any particular technique. This drawing is often performed by the conservators as a preliminary task to catch a glimpse of the artifact strata corrosion structure. As this method is currently used by conservators, they already have knowledge about this option. Thus, there is a conjunction from the concept “Drawing” to the knowledge “Drawing software”.

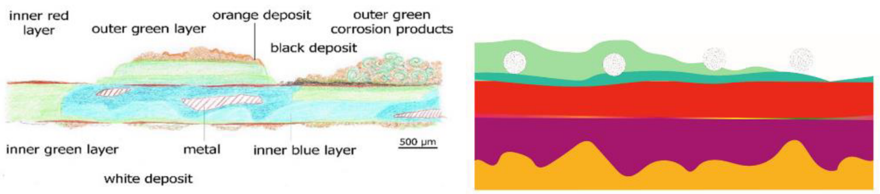

Fig. 3. Drawing using a pencil/paper method (left) and Adobe Illustrator [8] (right) © HE-Arc CR

Nevertheless, what really interests the conservators is a solution that utilizes Bertholon's conceptual model. Hence, our C-K framework will explore possible conjunctions based on this method. From the representation of a conceptual model, two other concepts arise. Once again, the representation can be performed using drawing techniques, either by hand or by computer. However, there is a difference from the previous conjunction, as the drawing will need to follow the methodology for representing stratigraphies. In addition, the drawing could be carried out within or without a framework. Drawing without a framework is what is currently performed by conservators once the artifact structure is known. Thus, a conjunction can be made from the concept of drawing to the knowledge of a drawing software which allows such visual representation. Then, this knowledge can be expanded to a knowledge of visual comparison (K → K) (Fig. 4). However, the conservators' idea is to follow the methodology developed by Bertholon to visually compare stratigraphies, using a common language [2]. Therefore, they now want to go further and be able to automatically compare stratigraphies between them.

On the other hand, drawing within a framework would provide the conservation professionals with a tool that could draw stratigraphies on a blank page with regard to what the conservators add as characteristics (Fig. 5). This idea was rapidly abandoned after being tested. Although it allowed characteristics to be automatically drawn, a similar problem to drawing without a framework occurred: automatic comparison was not possible. Indeed, we would have needed a tool that was able to perform image recognition in order to store the image and extract its characteristics.

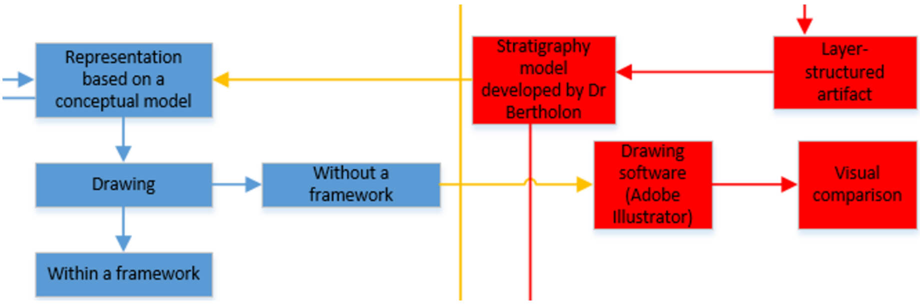

Fig. 4. The concepts that spring from the conceptual model representation (left) and their associated knowledge (right)

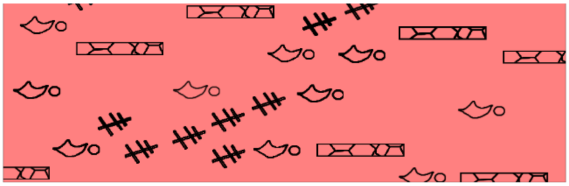

Fig. 5. The framework provided for conceptual model-based representation, tested and eventually abandoned

An alternative to drawing using exclusively the rules of a conceptual model is to expand from the knowledge of the different characteristics that can be used to represent the stratigraphies. Indeed, depending on the family it belongs to, a stratum can only be constituted of precise characteristics. The characteristics emerge from the stratigraphy model of Bertholon and allow the conservators to choose between a finite number of attributes to model their artifact structure. In this way, an ontology could be developed for representing the strata. Here, we use the term ontology as an explicit representation of concepts and their relationships [10] and not in its philosophical sense. The ontology could comprise all concepts needed in order to represent the artifacts, their stratigraphies, the strata, and the strata characteristics. However, due to the nature of the expected result, this option was not pursued. Nonetheless, it certainly makes sense to study this option in further research as such an ontology could assist the conservator in building stratigraphies while being assisted by its the inferences.

As the conservators know what the different characteristics of a stratum can be according to its family, a database which gathers this information can be set up. A disjunction can then be made to enable the use of data structures based on the characteristics included in the database. This data structure can later be utilized to generate pertinent drawings according to observed characteristics of the artifacts. Indeed, once a stratigraphy is designed, a representation based on the data structures can be generated if there is a drawing for each characteristic. Rules also need to be added to avoid the creation of an uninterpretable drawing due to too many colliding characteristics. Whereas the stratigraphy could be interpretable by a computer, it also needs to be visually understandable for a conservator, as the conservator will use it in his/her reports (Fig. 6).

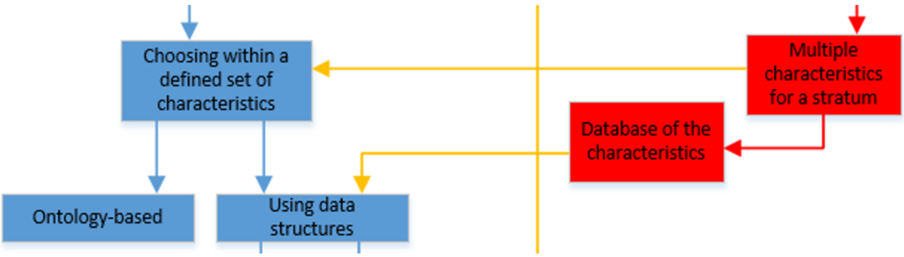

Fig. 6. The concepts embedded in the characteristics of the model developed by the conservators

Furthermore, comparison is made possible through the use of a database and data structures: the closer two stratigraphies are from each other, the higher the matching score of those stratigraphies is between them. Therefore, the database can use that score to return accurate stratigraphies according to the studied artifact. This allows the conservators to find other stratigraphies that are close to the one they study and to give them clues about which methods they could use in order to conserve their artifact [3]. As a result, a conjunction can be made from "Comparison" to "Search the database for similar stratigraphies" (Fig. 7).

In addition to comparison, images can be generated from the use of data structures, as the characteristics can be unequivocally drawn. We can therefore export the generated images to allow the conservators to include them in reports.

Joining the previously mentioned knowledge about DSS and the last two conjunctions, our tool is designed based on the knowledge created and mobilized by the interdisciplinary concepts and knowledge expanded in the C- and K-spaces. Thus, it addresses the conservators' needs to make use of a tool that is able to return similar stratigraphies and therefore help them in the diagnosis of ancient metal artifacts. Moreover, it allows them to export the built stratigraphies into an image that can easily be included in reports and analyses. The tool results from a concept that sprang from the conservation professionals. It was broken down into sub-concepts that activated knowledge from both the CR and IS fields and resulted in a founded solution.

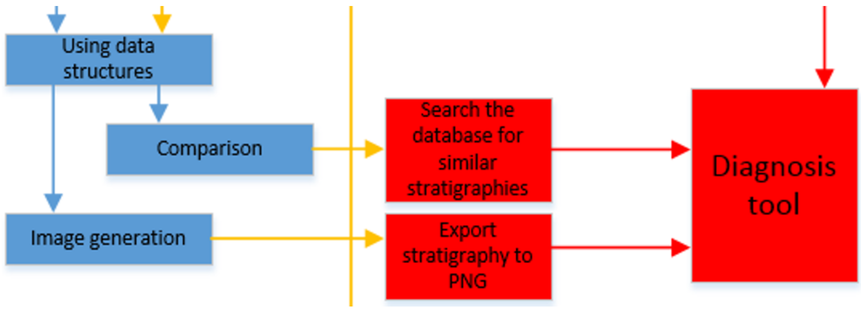

Fig. 7. Our application of the C-K theory led to the design of a diagnosis tool

4 Evaluating Knowledge Creation with C-K Theory

Using C-K theory allowed us to efficiently explore the different solutions that could be implemented. Moreover, it showed how knowledge coming from different fields can join to lead up to a usable and satisfactory solution. In addition, we noticed that our tool integrated concepts and knowledge that were developed throughout the expansion of both the C- and K-spaces. However, our tool cannot be used alone; other techniques (i.e. binocular observation and modeling the stratigraphies on Adobe Illustrator [8]) constitute preliminary steps in the diagnosis and comparison of heritage metal artifacts. Thus, our tool can be seen as the final component in the process of artifact diagnosis.

In our case, using the C-K theory first ensured that we covered most of the possibilities that constitute possible development of a diagnosis tool which could answer the conservators' needs. Moreover, breaking down their concept into sub-concepts allowed us to figure out the knowledge that was needed to be mobilized in order to expand both the C- and the K-space, as well as the conjunctions that could spring from this expansion. We also realized that the knowledge came from the IS and the CR fields and that we needed to merge to reach a satisfactory solution. The result of this process is a tool that embeds all the necessary elements the conservators need to complete the process of artifact diagnosis.

5 Discussion

Interdisciplinary research projects, given their orientation, are often the result of some power relations between different fields, not because of some sort of desire to monopolize the problem space, but because of some bias regarding the possible contributions of each fields. Choosing a method like C-K, which focuses on the C- and K-spaces assisted us in integrating concepts and knowledge from both fields as the research progressed and new refinements of the concepts space required new knowledge to be addressed. Each concept refinement provided an opportunity to seek expertise from the two fields in order to identify the possible extensions of the C-space. Likewise, it was the opportunity to bring knowledge on how to address the newly defined concept from two different points of view. This helped us integrate and build on the two visions of CR and IS at each step in the process.

The second contribution of C-K in this research is the post-mortem identification of the knowledge and concepts that build the core of the result. Given the two views that are integrated in the result, it could be seen as a black-box by people external to the process. In fact, IS researchers, bringing a specific set of knowledge and concepts, will probably come to a different solution on their own, simply given their lack of the C- and K-spaces of the CR field. The contrary is also true with CR researchers lacking the C- and K-spaces of the IS field. Therefore, without an explicit presentation of the various concepts and knowledge used in the process, it will be very difficult to understand not only the choices that were made during the process, but also the assumptions that the result is built upon.

Finally, by explicitly identifying the knowledge and concepts built into the process, users of the tool can better grasp its functioning as well as the required knowledge to use it effectively.

6 Conclusion

In this paper, we present an innovative way to design IS artifacts in an interdisciplinary context by relying on C-K design theory. By adopting the notions of concepts and knowledge spaces, we were able to bridge the expertise of the CR and IS fields in order to solve an interdisciplinary problem. Starting from a generic concept of the problem, the problem was iteratively refined, bringing new concepts from each field at each iteration. These refinements in turn were addressed with knowledge from both fields. Each refinement raised new challenges that needed to be addressed by combining expertise from the two fields. The resulting artifact, besides providing the expected support for the metal diagnosis of patrimonial objects, is also more valuable for the community because each decision and design choice can be linked to proper concepts or knowledge from the domains. This will support future researchers in finding areas of improvement, being able to rely on the K-space that was used to build the solution. It also provides an opportunity to review the artifact based on analyzing the proper usage of the various concepts and knowledge integrated in the process.

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