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Design Knowledge Interaction Model: A Proposal from a Cognitive Perspective

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Abstract: Generative artificial intelligence (GenAI) is widely used as a tool to inspire product designers, but there are limitations to ideate product concepts considering ergonomics and practicality. To overcome this limitation, the model is proposed by exploring the cognitive processes of product designers from the perspective of integrating Object Knowledge and Process Knowledge. This study aims to understand the designer's problem-solving process, systematize the diverse knowledge employed in this process, and establish a foundation for developing AI-based design tools applicable to design work.

Keywords: Design Knowledge, Design Process, Cognitive Process, Process Modelling, Knowledge Management

1 Introduction

Currently, generative artificial intelligence (GenAI) design tools have emerged as a significant topic in the design field. Extensive research has explored how designers utilize these tools throughout their processes, proving especially beneficial in the ideation phase for sparking inspiration and in the development phase for enhancing efficiency (Stige et al. 2023; Kim and Maher, 2023). However, in design fields that emphasize user experience and problem-solving, such as product design, the images generated by these tools often fail to fully meet user needs, particularly in terms of ergonomics and practicality (Tholander and Jonsson, 2023). In this context, the role of AI tools should not be to provide complete solutions but rather to assist designers in optimizing their design processes by enhancing cognitive thinking. Therefore, the development of AI design tools should not only focus on their output capabilities but also delve deeper into how product designers can more effectively collaborate with these tools to address challenges during the design process. This necessitates a more systematic study of how designers work and their cognitive processes during design, ensuring that AI tool development is more aligned with real-world design needs and better supports designers and users.

The design process for solving design problems is a comprehensive cognitive activity during the design stage. Understanding the cognitive processes involved in ideation is crucial for enhancing how designers interact with AI tools. Ideas are not randomly generated but are often structured by fundamental problem constraints, combining old and new information. In other words, ideation can be described as the process of acquiring, recalling, and reorganizing information and knowledge relevant to given problem conditions. The processing and utilization of abundant information and knowledge are crucial in the ideation process of design. GenAI tools can provide sources of knowledge to some extent, especially as tools for obtaining initial design inspiration (Kim and Maher, 2023; Liao et al. 2020). For example, when designing a mouse, one might use ChatGPT to inquire about the inconveniences of current mouse designs, or employ MidJourney to generate a variety of images that could inspire the mouse design. By understanding how designers receive and process the knowledge provided by artificial intelligence, and how this knowledge drives design, it helps to establish a more effective Human-AI design collaboration model, enabling designers to use AI tools more accurately to create solutions to complex problems.

Therefore, research is needed on the information cognition system of product designers who design while understanding the usage situations of product designs. Viewing the design process from the perspective of Cognitive Information Processing Theory, it can be considered a process of receiving input from external sources, processing that information, and producing output (Park and Lee, 1997). A similar perspective applies to the design process of AI design tools. Morris et al. (2023) delve into the development of Generative Models design space by introducing two distinct design spaces related to generative models: the input space and the output space. Within the input space, the manner in which users interact (Process) can significantly influence generative models (Object), while in the output space, the generated outcomes (Object), in turn, affect the methods of interaction (Process).

Product designers effectively employ accumulated Object Knowledge and Process Knowledge through extensive experience in problem-solving. In the process of solving problems related to the design project target, designers propose the final design outcome by constructing problem-solving design knowledge through the interaction of Object Knowledge about product attributes and Process Knowledge in building those attributes. The interaction between Object Knowledge and Process Knowledge can vary depending on the design goals, which are often shaped by how the product will be used in different situations. For example, in the case of designing a mouse, the designer utilizes Object Knowledge related to the hand and the shape of the mouse to create a design that is comfortable to hold. Process Knowledge is also employed to ideate and propose the final design by incorporating methods such as user testing and shape improvement for usability enhancement. In contrast, when designing a mouse with an experience-based interaction focus, like the Apple Magic Mouse, the designer observes user habits (Object Knowledge) and utilizes analysis methods (Process Knowledge) to propose new interaction methods. Similar to how the taste can vary based on the cooking process even with the same ingredients, achieving results aligned with the goal requires considering Process Knowledge alongside Object Knowledge. In the process, Object Knowledge related to users and mouse shape is commonly used, but its interpretation differs based on the design objectives. For example, when observing users' mouse usage scenarios (Object Knowledge) with a focus on comfort as the design objective, the designer extracts relevant Object Knowledge related to the suitability of hand and mouse shapes. On the other hand, when designing with a focus on interaction, more emphasis is placed on the user's manipulation style. Thus, although the input Object Knowledge is the same, the processing method (utilizing Process Knowledge) differs, resulting in different output knowledge.

To effectively utilize such organized knowledge in the product as a mouse, it is essential to understand designers' product ideation perspective, enabling the inspiration-derived data to be organized and used as knowledge. This allows artificial intelligence tools to be used more effectively. Consequently, this study aims to propose a model of knowledge interaction in the design process through theoretical review of design ideation processes from a cognitive perspective. The model seeks to explain the process of knowledge acquisition and utilization in design thinking, particularly during the cognitive process of resolving product issues in design projects. By examining the characteristics of the interaction between design Object Knowledge and Process Knowledge generated in the cognitive process of resolving product issues, the model describes the process of constructing and learning Object Knowledge and Process Knowledge based on the design goals of the outcome. This study also discusses the potential of using GenAI tools from the perspective of this model, providing a foundation for the development of artificial intelligence tools that are specifically designed to collaborate more effectively with human designers.

2 Research Frame

When viewed from the perspective of information processing, the designer's design process can be explained as an information processing procedure where the designer combines internal knowledge and experiential information stored in memory with external environmental and design target information. Currently, the perceptual system part of models related to cognitive processes is often explained as a bottom-up processing, receiving stimuli through the senses. However, according to the top-down processing theory of perception, the designer, even in the process of perceiving the external environment, is influenced by design objectives and the impact of episodic memory (experience) and semantic memory (knowledge) stored in memory (Goldstein, 2014). Processes such as how designers organize good works into files or Pinterest and the process of finding reference points depend on the influence of goals and existing knowledge. In other words, stimuli perceived through external environmental information, artifacts, and references are related to the designer's personal experiences and knowledge structure.

Newell and Simon (1972) described the problem-solving process as exploring the problem space to find a path between the statement of the goal and the solution to the problem. They engage in goal-oriented activities by exploring their problem space internally and finding solutions. In other words, the design problem-solving process can be explained as a process of seeking the optimal fit between the goal space, problem space, and solution space to overlap these three spaces. In the process of finding connections between these three spaces, a cognitive process is formed, consisting of perception, information processes, representation, and all available knowledge, where knowledge stored in memory and external information (surrounding information) interact. From this perspective, to explain the relationship between the triggering designer's cognitive process and the generated design knowledge, the basic frame is constructed as shown in [Figure 1].

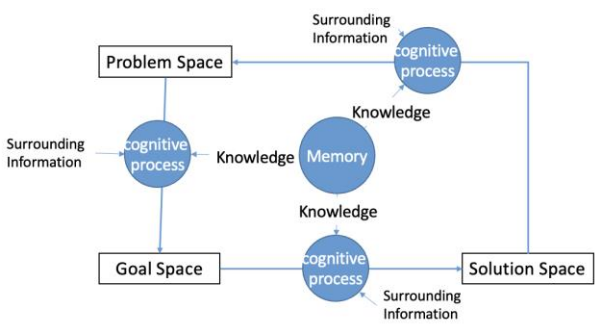

Figure 1. Basic Model Frame

3 Cognitive Perspective on the Design Process

3.1 Design Process and Design Spaces

The Double Diamond Design Process developed by the Design Council (2005) organizes the problem space and solution space as a process of repeating divergence and convergence of thoughts. Dorst and Cross (2001) explain that creative design involves continuously iterating the analysis, synthesis, and evaluation processes between the problem space and the solution space. Rather than first defining the problem and then finding a satisfactory solution, they describe the process of developing and improving ideas for problem understanding and solutions by repeatedly iterating between the problem space and the solution space.

Johnsey (1995) analyzed and compared models of 17 design or problem-solving processes from 1971 to 1995, dividing the design process into 12 stages: Problem Identification, Clarifying Control Factors, Setting Design Goals, Researching Specific Information Related to the Problem, Generating Solutions, Selecting from Possible Alternatives, Modeling Ideas, Planning Production, Making, Testing, Modifying, and Evaluating. Among these 12 stages, the stages of Problem Identification and Clarifying Control Factors involve analyzing the problem in the problem space. Setting design goals is the connection between the problem space and the goal space, and in the process of evolving from the goal space to the solution space, the stages of generating/modifying solutions are generated. Selecting, modeling, planning, making, testing occur in the developmental process of the solution space, and evaluation, as it discovers problems with the current solution, connects the solution space to the problem space. Data collection can occur in both the solution space and the problem space. The concept of 'goal subdivision,' setting sub-goals in the goal space, was added following the theories of Minsky (1988).

Kelly (1987) summarized this design process into four stages: Identifying needs and opportunities, Generating a design, Planning and making, and Evaluating. When combined with design space theory, Identifying needs and opportunities occur in the process from the problem space to the goal space, Generating a design in the process from the goal space to the solution space, and Evaluating in the process from the solution space to the problem space. Planning and making represent the process of developing the solution space through design actions.

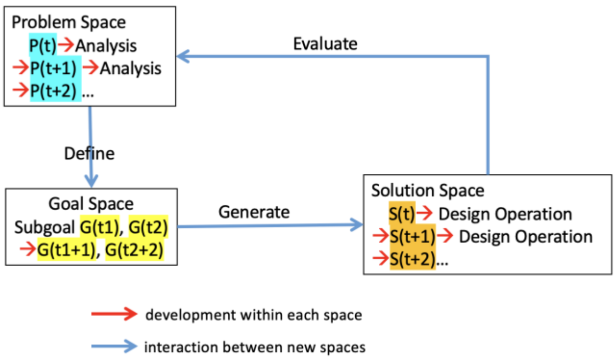

Figure 2. the development of Problem Space - Design Goal Space - Solution Space

From this perspective, the current study constructs a design process frame [Figure 2] by defining design objectives through analysis of the problem space, generating a solution space according to the objectives, evaluating the solution space, and discovering new problems. The development of the problem space occurs through two paths: (1) exploration, discovery, and analysis within the problem space, and (2) expanding the problem space through the discovery of new problems during the evaluation of solutions. The development of the goal space involves two paths: (1) decomposition into smaller sub-goals through goal analysis and (2) defining new goals through new interpretations of the problem space. The development of the solution space also has two paths: (1) reversing solutions through design actions such as idea selection, sketching, and prototyping within the solution space, and (2) generating new solutions through the discovery of problems, goal definition, and solution modification during solution evaluation. In summary, the development of each space involves (1) interaction between new spaces and (2) development within each space.

3.2 Human Information Processing and Design Process

Based on Card, Moran, and Newell's theory(1983), human information processing is the result of the interaction between perceptual, cognitive, and motor systems, along with Memory. According to the bottom-up processing theory of perception, the designer's process of perceiving the external world is the result of the common interaction between internally stored knowledge in Memory and external stimuli. The designer perceives objects in the external world through senses like vision, hearing, and touch. This information is then stored in Working Memory and processed systematically by the Cognitive Processor, utilizing knowledge stored in Long-term Memory. The processed results are output through the Motor Processor. Throughout this process, information is stored in Working Memory and, when necessary, replayed for utilization in the desired context. The information processing involves storing important information from Working Memory into Long-term Memory, contributing to learning.

The Cognitive-Design Process Frame [Figure 3] have been constructed by adding the Cognitive Process module to the frame of [Figure 2]. In the Cognitive Processor, the problem space is analyzed, design objectives are defined, and relevant knowledge stored in Memory is activated and retained in Working Memory according to the objectives. Solutions are generated through various Cognitive Processes such as combination and transformation. The Motor Processor advances the solution through design actions such as sketching. The design created through the Perceptual Processor is perceived, and, upon reevaluation by the Cognitive Processor, problems are identified, updating the problem space. Additionally, external information stored in the design folder, such as cases and design references, is stored in Working Memory through the Perceptual Processor for subsequent use in the design process.

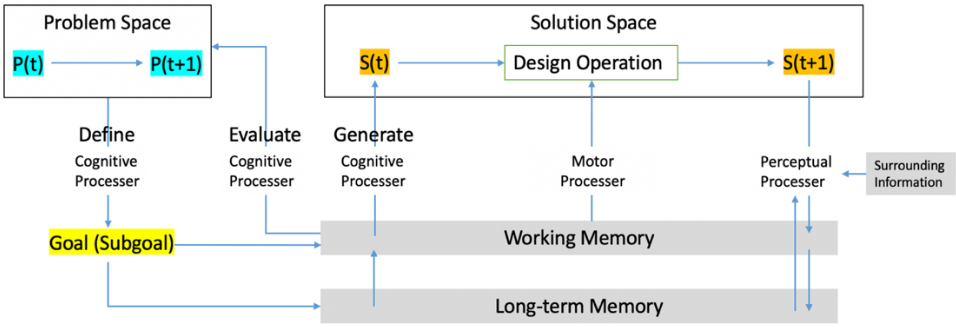

Figure 3. Cognitive-Design Process Frame

Cognitive Processor is described by Finke et al. (1992) as a design cognitive process that iteratively generates ideas for problem-solving through the repetition of the generation (Generate) process and the exploration (Explore) process. The generation process involves memory retrieval, association, and transformation, while the exploration process includes problem analysis and solution analysis. Benami and Jin (2002) suggest that the design cognitive process brings design entities into operation and that the newly created design entities stimulate design cognition again through design operations.

Goldschmidt (1990) defined design operations as "inferential acts that propose consistent proposals related to the entity being designed." Suwa et al. (2000) classified design actions into physical actions (direct actions such as physically describing on paper), perceptual actions (actions that focus attention on spatial and temporal features), and conceptual actions (goal-setting). Thus, in this study, design actions encompass the perceptual, cognitive, and physical aspects of the designer's cognitive process, while design operations are actions expressing what is in the designer's mind.

Jin and Benami (2010), building on Goldschmidt's definition, classifyed operations into internal and external ones. Internal Operations deal with the strategy and stages of design, while external Operations process physical symbols and representations. Internal Operations, inferred from the think-aloud protocol data of the design process, include suggesting, computing, questioning, declaring, supposing, and explaining. External Operations involve speaking, writing, sketching, pointing, and simulating.

In the design cognitive process, internal operations involve the process of explicit knowledge transfer from working memory, while external operations represent the external expression of knowledge to facilitate knowledge sharing. Building on the explanations of the cognitive and motor processors, we refined the cognitive part of the Cognition in the Design Process and developed a model for the interrelation of design goals, design actions, and object knowledge in [Figure 4].

Accordingly, based on design goals, relevant knowledge stored in long-term memory is activated. Through perceptual processor exploration and generation, the problem is interpreted, and relevant knowledge is selected, combined, and transformed. The transformed knowledge is stored in working memory, converted into ideas or visual design entities through design actions. Object knowledge obtained through perceptual processor input becomes the input knowledge. During the cognitive stage, the input knowledge is interpreted and reconstructed, and through the motor processor, the reconstructed knowledge is output. The outputted object knowledge (design entity) stimulates perception and becomes input knowledge again. Process knowledge is used in the design cognitive-action stage and is stored in working memory. As the design progresses, crucial object knowledge and process knowledge stored in working memory are integrated into relevant 'K-lines'(Minskey,1980) in long-term memory to facilitate recall in similar situations in the future.

The development processes of the problem space and solution space, along with the exploration and generation processes in the Cognitive Processor, were mapped based on the design process stages and design cognitive processes. The process begins with collecting data on the problem and recognizing it through the recollection of personal experiences and existing knowledge. Problem analysis, including factors analysis, is performed to explore the problem space and set design objectives. Retrieving relevant knowledge from memory based on the design objectives leads to the collection of information about potential solutions, forming the solution space. The analysis of relevant data can be described as exploring the solution space.

In the solution space, knowledge is combined, associated, and transformed to generate new knowledge, updating the solution space. Through internal design operations, ideas are formed, or through external operations, ideas are visualized and expressed. Solution evaluation/analysis leads to the discovery of new problems, updating the problem space. This iterative process of exploring the problem space, generating solutions, searching the solution space (evaluating/analyzing solutions), and advancing the problem space is repeated to generate and refine ideas.

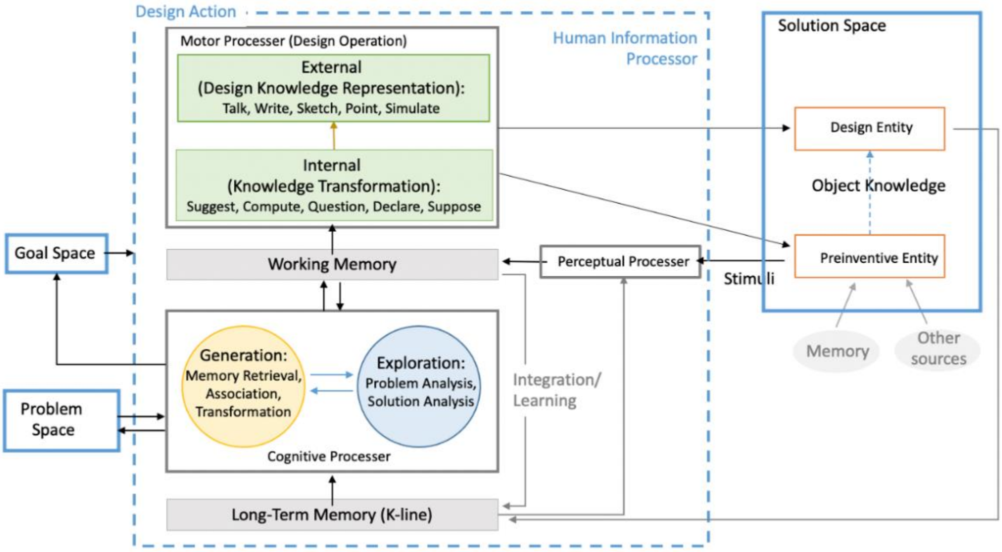

Figure 4. The model for the interrelation of design goals, design actions, and object knowledge

4 Knowledge Interaction in the Design Process of Problem Solving

4.1 Design Knowledge

Alexander et al. (1991) defined knowledge as "...an individual's inventory of information, skills, experiences, beliefs, and memories." Knowledge, unlike information, includes the will and purpose of the performer. While information can be stored in information systems, knowledge is embodied in humans. Knowledge creation is a highly human act (Friedman, 2000). Information is on the 'input' side before human processing, while knowledge is on the 'output' side after processing.

Many studies in cognitive psychology have demonstrated the significant relevance of knowledge in understanding problem-solving (Larkin and Simon, 1987; Goldstein, 2014). In the field of design, numerous studies (Oxman, 1990; Schon, 1984) explain the significant impact of understanding the problem and knowledge about the design subject on creative design.

Knowledge can be classified in various ways depending on the perspective. In this study, design knowledge is classified into Design Object Knowledge and Process Knowledge. Object Knowledge is classified into Appearance (e.g., shape, material, structure, etc.), Function (e.g., functionality), and Behavior (e.g., user habits) based on studies by Gero (1990) and Umeda et al. (1996). These three types of Object Knowledge collectively constitute the Design Entity.

Process Knowledge involves overarching problem-solving methods for producing design outcomes and is typically implicit. Eraut (2000) categorizes implicit knowledge into three types: Implicit Understanding of People and Situations, Regular Behavior, and Implicit Rules Supporting Intuitive Decision-Making. Anderson (1982) defines procedural knowledge as the understanding of how to perform actions crucial for goal attainment. Conditional knowledge, on the other hand, pertains to knowing when to apply appropriate declarative and procedural knowledge in various situations. Procedural knowledge aligns with Eraut's classification of regular actions, while conditional knowledge corresponds to implicit rules that facilitate intuitive decision-making.

In this study, Process Knowledge is segmented into (Kp1) Understanding of situations and objects (e.g., analyzing existing products based on experience), (Kp2) Rules supporting decision-making and causes for design actions (e.g., adjusting the size of a mouse based on hand size comparison), and (Kp3) Methods and justifications for selecting and transforming design elements (e.g., extracting relevant knowledge from memory based on acquired knowledge), in accordance with Eraut's classification method.

4.2 Utilization of Design Knowledge in the Design Process

To analyze the roles of the three types of Design Process Knowledge at each stage of the design problem-solving process and cognitive process, we referred to Thoring and Mueller's model(2012) of design knowledge levels. The relationship between design knowledge levels can be described as follows: Level A encompasses the external representation of design object knowledge, including design cases, the user environment, design sketches, outcomes, etc., collectively referred to as Design Entities. Level B involves the process knowledge used in the design cognitive processor. Level C represents design object knowledge obtained through internal design actions in the motor processor (e.g., Suggest, Compute, Question, Declare, Suppose). The evolution of knowledge from Level A to Level C involves filtering and reconstructing knowledge through the perception of the environment and objects, utilizing (Kp1) understanding of situations and objects and (Kp3) knowledge of selecting and transforming design elements. From Level C to Level A, knowledge is expressed and externalized through design actions, utilizing (Kp2) knowledge about the rules and methods of design actions.

Integrating with the design ideation process, the utilization of Kp1, understanding situations and objects, is coupled to analyze design cases at Level A and extract design Object Knowledge embedded in the physical form. By leveraging Kp3, knowledge about selecting and transforming design elements, relevant design Object Knowledge is chosen based on the design objectives. The selected knowledge is then applied using Kp2, knowledge of rules and methods for design actions, to visually express it (Level A) or obtain new Object Knowledge (Level C) through knowledge combination and rearrangement. The resulting visual representation or new knowledge is evaluated (Kp1), leading to new insights (Level C). This iterative process is repeated to complete the final design.

4.3 Evolution of Design Knowledge

In Sim and Duffy's (2003) model of the evolution of design knowledge, the Design Knowledge Evolution process initiates with the design goal (Gd) and pertinent pre-existing knowledge (Input Knowledge - Ik). The designer engages in design actions (Ad) to reach the goal, and in this course, knowledge transfer takes place, leading to the emergence of new knowledge (Output Knowledge - Ok).

Building on this, the evolution of design knowledge can be visualized using the Linkography method (Goldschmidt, 1990), where design moves are represented as nodes connected by links, reflecting the designer's intent and the associated design Object Knowledge.

In [Figure 5], a design goal (G1) leads to a design action (Ad1), generating Output Knowledge (Ok1). This knowledge can also serve as Input Knowledge (Ik1) for another action (Ad2). Such knowledge connections are depicted in Linkography as nodes (Ok1-2/Ik2-1) connecting the actions (Ad1 and Ad2).

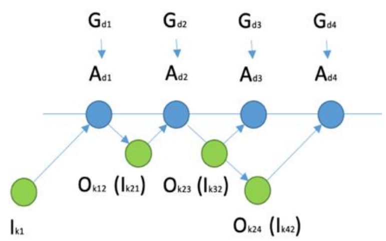

Figure 5. Design Knowledge Evolution Process

Through the analysis of the relationship between moves and nodes in Linkography, the evolution of design goals (intentions) and the development of Object Knowledge, along with the utilization process of Process Knowledge, can be concretely illustrated. From this perspective, design Object Knowledge evolves through design actions, while Process Knowledge reflects and evolves through the evaluation of design outcomes and processes.

5 Design Knowledge Interaction Model

Building upon the proposed interaction process of design knowledge, a model explaining the given design problem-solving process is presented in [Figure 6]. In this model, the exploration-related aspects of the Cognitive Process are indicated in blue, the generation-related aspects are shown in yellow, and the Motor Processor-related parts are represented in green.

The designer explores and interprets the problem, setting the design goal (Goal). Activating the relevant Design Object Knowledge (Ko) and Process Knowledge (Kp) stored in Long-term Memory, as indicated by the yellow arrow direction. By utilizing Kp3, the methods for selecting and transforming design elements (shown in yellow), the designer chooses design elements (Ko input). Through Kp2, the rules and methods of design actions (indicated in green), the designer performs design actions (Design Action), updating the design solution space (Ko output). Kp1, the knowledge related to understanding the situation and objects (shown in blue), is then used to evaluate the new design solution, discover new problems, and update the problem space. This cyclical process involves setting new goals based on the problem, searching for relevant knowledge again. The results of evaluating the design solution and design process guide the reflection on the appropriateness of the utilized Process Knowledge (Kp), which is then stored in Memory for reference in solving similar design problems.

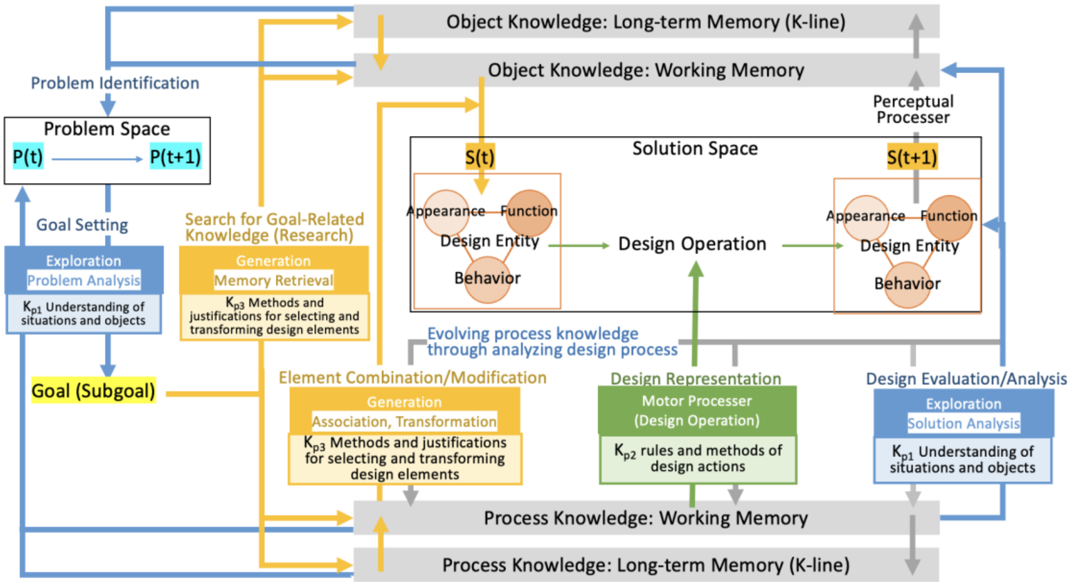

Figure 6. Design Knowledge Interaction Model from a Cognitive Perspective

From the perspective of knowledge evolution and cognitive learning, this process involves perceiving stored knowledge or related information through Memory, transforming it into input knowledge during the perception phase, interpreting and reconstructing the input knowledge during the cognitive stage, and outputting the reconstructed knowledge through the Motor Processor. The outputted Object Knowledge (Design Entity) then stimulates perception, completing the cycle where it becomes input knowledge again. Process Knowledge is employed in the design cognitive-action stage and is stored in Working Memory. Essential Object Knowledge and Process Knowledge stored in Working Memory are integrated into the relevant K-line in Long-Term Memory, allowing for recall in similar situations in the future.

For example, in the design of a mouse, the designer activates object knowledge such as the way the mouse is used, the structure of the mouse, and process knowledge such as methods for investigating user needs based on the design goals for a mouse that fits the user's habits. By observing (action) and analyzing (Kp1) the process of users using existing mouse products (Object Knowledge (Input)), the designer gains knowledge (Object Knowledge (Output)) related to user habits. The newly acquired knowledge becomes the input for the next stage, and the designer uses process knowledge to propose a design by combining interaction methods tailored to user habits with functions and forms. The design is then tested, evaluated, and modified, not only assessing the design outcome but also reconsidering whether the used Object Knowledge and Process Knowledge are appropriate. The knowledge database consisting of K-lines is updated in this process.

6 Discussion: Potential of GenAI in Design from a Cognitive Perspective

Haritaipan (2019) analyzed 112 tangible tools aimed at supporting designers' practice and creativity and identified two main strategies for enhancing creativity with tangible tools: (1) providing inspiration and (2) prompting designers for action. The first strategy stimulates designers' creativity by offering Object Knowledge, which encompasses various forms of specific information and ideas that can spark creative thinking. The second strategy involves supplying Process Knowledge, including instructions and methods, which guide designers through their workflow and decision-making processes. Building on this, Liao et al. (2020) presented three potential roles of AI-based inspirations in ideation: AI as a creator of representations, AI as an empathy trigger, and AI as a means of engagement. These roles, when integrated with the model proposed in this study, can be represented visually in Figures 7,8 and 9.

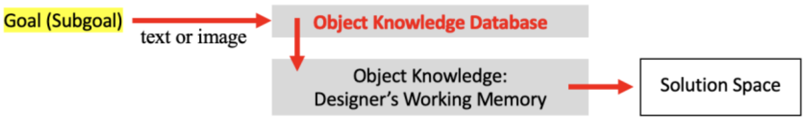

Figure 7. AI as representation creation

Once designers have established their goals, they begin to gather necessary references (Object Knowledge) to spark inspiration [Figure 7]. The collected data then enters the designer's working memory, where it is processed and integrated with their existing knowledge. This integration is key to stimulating the creation of innovative solutions. In comparison to traditional methods of information search, which are limited by the resources available and the designer's ability to access specific information, AI tools use algorithms to swiftly extract and recommend Object Knowledge that is semantically or visually relevant from extensive databases. This Object Knowledge fosters analogical thinking, where designers relate one attribute to another, forming connections across different concepts (Ball & Christensen, 2009,). This form of thinking is essential in design ideation. Research by Kim & Maher (2023) has demonstrated that AI models focused on conceptual similarity significantly enhance the novelty, variety, and quantity of ideas generated during the design ideation process. This underscores the role of GenAI in providing inspiration by offering texts or images that align with the designer's conceptual goals.

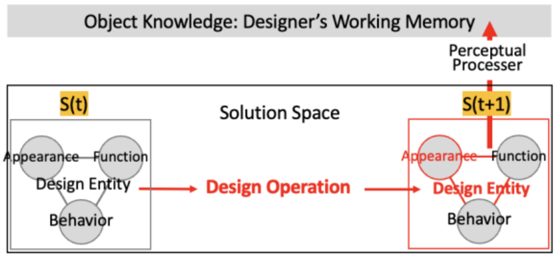

Figure 8. AI as an empathy trigger

After initially conceiving a basic idea for a solution, designers can employ GenAI tools such as MidJourney to visualize the idea[Figure 8]. While current GenAI tools like MidJourney primarily excel in depicting appearance and often lack a deep understanding of function and user behavior, which can result in product images that lack logical coherence, the deviation of AI-generated images from the designer's initial vague concepts can actually foster reflective thinking. This process enables designers to articulate their design concepts more clearly, analogous to how designers visualize a client's vague requirements during interactions to clarify expectations (Le and Jung, 2020).

On the other hand, the unusual and illogical images produced by AI can sometimes provide new inspiration. Unlike the previous step where AI provides triggers based on context (design goals), in this phase, the AI can act as "random triggers," as identified by Haritaipan (2019). These triggers offer designers a wide range of aspects to inspire novel ideas, moving beyond the constraints of the initial design context. According to Bernal et al. (2015), the abstract and unconventional results from AI are likely to trigger "unpredictable inferences," which are extremely valuable in early design activities where flexibility and exploration are encouraged. These unpredictable outcomes can open up new avenues for creativity, helping to expand the horizon of what is possible in design solutions. This process enriches the creative workflow, allowing designers to explore beyond conventional boundaries and incorporate fresh, innovative perspectives into their projects. By leveraging these random triggers, designers can tap into a broader spectrum of creative possibilities, fostering a dynamic and expansive approach to design ideation.

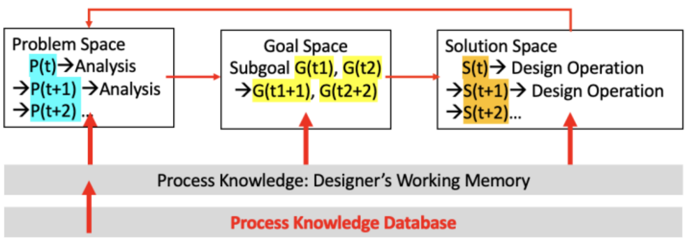

Figure 9. AI as engagement

The first two roles of AI focus on enhancing the designer's ability to make analogical connections by providing Object Knowledge, while the third role involves actively helping designers avoid fossilization and perform typical design actions.

Process Knowledge encourages interaction between the problem space, goal space, and solution space, thus fostering development within and across these spaces[Figure 9]. Many existing design toolkits, such as the Human-Centered Design Toolkit by IDEO (2009) and the Service Design Toolkit by Namahn (2014), offer such Process Knowledge. Unlike these traditional design toolkits, which require designers to initiate use when they encounter obstacles, AI is expected to proactively act as a trigger for design actions, thereby driving designers to reframe their approach (Liao et al. (2020). For example, AI could predict when designers are stuck at barriers and subsequently provide targeted instructions or pose questions to help them navigate out of these obstacles. This proactive capability positions AI not just as a tool, but as an active participant in the design process, poised to assist designers in overcoming challenges and pushing the boundaries of traditional problem-solving methods. Many design firms are exploring these capabilities, and programs like the Adobe Photoshop Improvement Program collect data on how designers use the software to identify trends and usage patterns. However, a significant challenge in this area is understanding and modeling designer behavior, as designers employ various styles of thinking across different stages and individuals. The complexity of accurately capturing and modeling these behaviors necessitates further research into developing methods for building effective Process Knowledge Database.

7 Conclusion

This study aimed to explain the process of constructing and utilizing design knowledge from a cognitive perspective during the problem-solving process and to describe the interaction processes and characteristics of Object Knowledge and Process Knowledge based on design objectives. To achieve this objective, we reviewed prior research in cognitive science theories, the design problem-solving process, and design knowledge. Subsequently, we proposed a model of knowledge interaction during the design ideation process, termed the "Design Knowledge Interaction Model from a Cognitive Perspective", and discussed the potential of using GenAI tools from the perspective of this model. The study revealed that the interaction between Object and Process Knowledge occurs cognitively within the designer's mind during the design process. Current AI design tools are adept at triggering inspiration by providing Object Knowledge, which can help designers generate initial ideas and concepts. However, these tools often have limitations when it comes to supporting the construction of Process Knowledge, which is essential for facilitating the designer’s cognitive processes.

Through this research, we illuminated the ideation process of designers reflected in design outcomes, systematizing the diverse knowledge used in the process, especially focusing on the interaction between Object Knowledge and Process Knowledge during the design process. By understanding the cognitive aspects of design and the interaction of design knowledge, we aim to provide a foundation for the development of artificial intelligence tools aimed at more effectively collaborating with human designers. The long-term goal is to contribute to the development of artificial intelligence design tools by enhancing our understanding of how human designers think. If AI tools can comprehend the interaction and utilization processes of Design Object Knowledge and Process Knowledge, they can provide insights that assist designers in achieving more accurate and specific design ideation.

The primary limitation of our current research is its theoretical focus, which lacks empirical validation. To address this, in subsequent studies, we plan to conduct long-term observational experiments to observe and compare how designers utilize process knowledge and object knowledge provided by artificial intelligence design tools. This will allow us to examine the evolution and reuse of design knowledge and explore more effective collaboration models between artificial intelligence and human designers. Additionally, we will investigate methods for structuring knowledge into a system that artificial intelligence can understand. Based on these findings, we will discuss the direction of new design tools based on the cognitive processes of the design knowledge interaction model proposed in this study.

References

Anderson, J. R., 1982. Acquisition of cognitive skill. Psychological Review, 89(4), 369-406. https://doi.org/10.1037/0033-295X.89.4.369

Alexander, P. A., Schallert, D. L., & Hare, V. C., 1991. Coming to terms: How researchers in learning and literacy talk about knowledge. Review of Educational Research, 61, 315-343. https://doi.org/10.3102/00346543061003315

Ball, L. J., & Christensen, B. T., 2009. Analogical reasoning and mental simulation in design: Two strategies linked to uncertainty resolution. Design Studies, 30(2), 169-186. https://doi.org/10.1016/j.destud.2008.12.005

Benami, O., & Jin, Y., 2002. Creative stimulation in conceptual design. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 3624, pp. 251-263). https://doi.org/10.1115/DETC2002/DTM-34023

Bernal, M., Haymaker, J. R., & Eastman, C., 2015. On the role of computational support for designers in action. Design Studies, 41(Part B), 163-182. https://doi.org/10.1016/j.destud.2015.08.001

Card, S. K., Newell, A., & Moran, T. P., 1983. Chapter 2. The Human Information-Processor, In The Psychology of Human-Computer Interaction.

Chacón, J. C., Nimi, H. M., Kloss, B., & Kenta, O., 2021. Towards the Development of AI Based Generative Design Tools and Applications. In Design, Learning, and Innovation: 5th EAI International Conference, DLI 2020, Virtual Event, December 10-11, 2020, Proceedings 5 (pp. 63-73). Springer International Publishing. https://doi.org/10.1007/978-3-030-78448-5_5

Christiaans, H., & Venselaar, K., 2005. Creativity in design engineering and the role of knowledge: Modelling the expert. International Journal of Technology and Design Education, 15(3), 217-236. https://doi.org/10.1007/s10798-004-1904-4

Dehman, H., 2023. Graphic design, Already Intelligent? Current possibilities of generative AI applications in graphic design.

Dorst, K., & Cross, N., 2001. Creativity in the design process: co-evolution of problem-solution. Design studies, 22(5), 425-437. https://doi.org/10.1016/S0142-694X(01)00009-6

Eraut, M., 2000. Non-formal learning and tacit knowledge in professional work. British Journal of Educational Psychology, 70(1), 113-136. https://doi.org/10.1348/000709900158001

Finke, R. A., Ward, T. B., & Smith, S. M., 1992. Creative cognition: Theory, research, and applications. MIT Press.

Friedman, K., 2000. Creating design knowledge: from research into practice. IDATER 2000, 1, 28.

Goldschmidt, G., 1990. Linkography: assessing design productivity. In Cybernetics and System '90, (Trappl, R., Ed.), pp. 291-298. World Scientific, Singapore.

Goldstein, E. B., 2014. Cognitive Psychology: Connecting Mind, Research and Everyday Experience. Cengage Learning.

Gero, J. S., 1990. Design prototypes: a knowledge representation schema for design. AI magazine, 11(4), 26-26.

Haritaipan, L., 2019. Towards the Creation of Creativity Tools for Real-practice: A Review of 112 Design Tools in the Market. The Design Journal, 22(4), 529-539. https://doi.org/10.1080/14606925.2019.1613800

Hori, K., 1997. Concept space connected to knowledge processing for supporting creative design. Knowledge-Based Systems, 10(1), 29-35. https://doi.org/10.1016/S0950-7051(97)00011-7

Johnsey, R., 1995. The design process-Does it exist?. International Journal of Technology and Design Education, 5(3), 199-217. https://doi.org/10.1007/BF00769904

Kelly, A. V., et al., 1987. Design and Technological Activity -A Framework for Assessment. APU/HMSO, London.

Kim, J., & Maher, M. L., 2023. The effect of AI-based inspiration on human design ideation. International Journal of Design Creativity and Innovation, 11(2), 81-98. https://doi.org/10.1080/21650349.2023.2167124

Larkin, J. H., & Simon, H. A., 1987. Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11, 65-99. https://doi.org/10.1111/j.1551-6708.1987.tb00863.x

Le, M., & Jung, E. C., 2020. Analysis of intent-design relationship for artificial intelligence design agent model based on product purchasing process. In Proceedings of the Design Society: DESIGN Conference (Vol. 1, pp. 285-294). Cambridge University Press. https://doi.org/10.1017/dsd.2020.146

Liao, J., Hansen, P., & Chai, C., 2020. A framework of artificial intelligence augmented design support. Human-Computer Interaction, 35(5-6), 511-544. https://doi.org/10.1080/07370024.2020.1733576

Liu, C., Ren, Z., & Liu, S., 2021. Using design and graphic design with color research in AI visual media to convey. Journal of Sensors, 2021, 1-11. https://doi.org/10.1155/2021/5618538

Minsky, M., 1980. K-Lines: A theory of Memory. Cognitive Science, 4(2), 117-133. https://doi.org/10.1016/S0364-0213(80)80014-0

Minsky, M., 1988. Society of Mind. Simon and Schuster. https://doi.org/10.21236/ADA200313

Morris, M. R., Cai, C. J., Holbrook, J., Kulkarni, C., & Terry, M., 2023. The design space of generative models. arXiv preprint arXiv:2304.10547.

Newell, A., & Simon, H. A., 1972. Human Problem Solving. Englewood Cliffs, NJ: Prentice-Hall.

Oxman, R., 1990. Prior knowledge in design: a dynamic knowledge-based model of design and creativity. Design studies, 11(1), 17-28. https://doi.org/10.1016/0142-694X(90)90011-Z

Park, Y. M., & Lee, D. Y., 1997. A study on the Cognitive Scientific explanation for Design Ideation. Archives of Design Research, 1-12.

Schön, D. A., 1988. Designing: Rules, types and worlds. Design studies, 9(3), 181-190. https://doi.org/10.1016/0142-694X(88)90047-6

Sim, S. K., & Duffy, A. H., 2003. Towards an ontology of generic engineering design activities. Research in Engineering Design, 14(4), 200-223. https://doi.org/10.1007/s00163-003-0037-1

Stige, Å., Zamani, E. D., Mikalef, P., & Zhu, Y., 2023. Artificial intelligence (AI) for user experience (UX) design: a systematic literature review and future research agenda. Information Technology & People. https://doi.org/10.1108/ITP-07-2022-0519

Suwa, M., Purcell, T., & Gero, J., 1998. Macroscopic analysis of design processes based on a scheme for coding designer' cognitive actions. Design studies, 19(4), 455-483. https://doi.org/10.1016/S0142-694X(98)00016-7

Thoring, K., & Mueller, R. M., 2012. Knowledge Transfer in Design Education: A Framework of Criteria for Design Exercises. In DS 74: Proceedings of the 14th International Conference on Engineering & Product Design Education (E&PDE12) Design Education for Future Wellbeing, Antwerp, Belguim, 06-07.9. 2012 (pp. 153-158).

Umeda, Y., Ishii, M., Yoshioka, M., Shimomura, Y., & Tomiyama, T., 1996. Supporting conceptual design based on the function-behavior-state modeler. Ai Edam, 10(4), 275-288. https://doi.org/10.1017/S0890060400001621

Walls, J. G., Widermeyer, G. R., & El Sawy, O. A., 2004. Assessing information system design theory in perspective: how useful was our 1992 initial rendition?. Journal of Information Technology Theory and Application (JITTA), 6(2), 6.

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