Design as Knowledge Generation Process By Reasoning

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Abstract: During the design process, designers learn about artifacts, environment, stakeholders and their goals/values in various contexts with research activities. Such data lead to creative insights, through designers' inductive, deductive, abductive, and analogical reasoning. The four reasoning processes are, in fact, parts of a continuous process in that analogy is at the base of all other processes, induction starts from abduction, and deduction starts with induced rules. In this study, Michalski's eight pairs of knowledge transmutation operations that employ all abduction-induction, deduction, and analogy types of inferences are elucidated with empirical data collected from a service design workshop, to show how the reasoning processes emerged in the workshop participants' specific actions that led to generation of new knowledge.

Key words: Reasoning, Knowledge transmutation, Design creativity

1. Introduction

Design is one type of creative process where courses of action are devised to change existing situations into preferred ones [13]. Often designers start their projects from defining the problem situation, by identifying relevant factors and analyzing how the factors are linked to observed problem phenomena. During the process, they rely on both experiential knowledge to collect perceptible evidences, and theoretical knowledge to develop conceptual explanations. Simultaneously, designers explore solution ideas by looking at available technology, material, form, function and structure. What connects the problem analysis and solution synthesis is the designer's hypotheses of how the defined problems are going to be solved with the proposed solutions. To find reliable hypotheses, most designers would think that they rely on intuitive judgment, or so-called *hunch,* coming from their prior experiences. This study argues that the seemingly intuitive solutions are in fact products of their background knowledge transformed with logical and analogical reasoning, and a designer's creativity lies in her ability to transform knowledge gained from the problem and solution spaces, to recognize the latent relevancy between them.

In this paper, regarding how the designer's knowledge is transformed, the author will (a) review existing theories of logical and analogical types of reasoning and models of design creativity to find out how reasoning is involved in the creative process, (b) illustrate how the reasoning processes apply to particular actions designers take, with empirical data collected from a service design project, and (c) clarify how the reasoning processes are related to a designer's experiential-theoretical background knowledge and four area of design expertise, in a diagrammatic model. The definitions of different reasoning processes (induction, deduction, abduction, and analogy) continue in the next section.

2. Theoretical background

2.1 Induction, Deduction, Abduction, and Analogy Types of Reasoning

Three types of logical reasoning—induction, deduction, and abduction—are defined as follows [12]: deduction is an act of drawing conclusions by examining a case against given rules, while in induction, rules are induced from many connected observations over time. With abduction or hypothesis, rules are given and observations can be made, but the relationship between the rules and observations (i.e., case) are not obvious, so it is guessed considering the rules, observations, and the thinker's background knowledge.

Regarding how the three processes are related, Merrel argues that the process of abduction, in fact, precedes deduction and induction, because a person has to have a hypothesis (abduction) before applying it to a larger set and making it a confirmed thesis (induction). Later, more cases will be evaluated against this confirmed thesis (deduction). Induction, deduction, and abduction are a matter of how certain you are about a thesis: you can start by hypothesizing it; then establish it as a reliable fact with many evidences (cases) that support it; later you can evaluate other propositions based on it [10].

Furthermore, abduction (hypothesis) is treated as part of other inductive or analogical reasoning by Michalski [11, p. 16]. For example, generalization is one type of knowledge transmutation that can be all inductive, analogical or deductive, and Michalski sees inductive generalization as taking "descriptions of some objects from a given class […] and *hypothesizes* a general description of the class", and analogical generalization as "[hypothesizing] a general description of the given fact by analogy to the generalization of similar facts." His definition of deductive generalization is somewhat different in that it is "[deriving] a more general description from a more specific one by deducing it from the background knowledge". Michalski theorizes that knowledge transmutation involving induction, analogy or contingent deduction (i.e., plausible deduction of consequences) leads to generation of new knowledge, so it is a *synthetic* process, while knowledge transmutation with conclusive deduction produces only derived knowledge, so it is an *analytic* process.

The *logical* reasoning processes of induction, deduction, and abduction have been contrasted to a different type of reasoning process, *analogical* reasoning. Gentner et al. explains analogy as a type of inference where major changes are made in one's current theory/knowledge by considering and applying the common structure between two cases, from a well-articulated source domain to a less coherent target domain [2, p. 6]. For analogical reasoning, the thinker starts from *highlighting* the matching structural aspects between the source and target to gain manageable subsets of information, *projecting* tentative inferences to the target domain, *representing* either or both domains to find better matching structures, and ends in *restructuring* the target domain to make final explanations more coherent, by adding or deleting elements and relationships in the target domain. By going through the process, the thinker can change either her current concepts or the theoretical structure relating the concepts; then, creative ways to define or explain the concept are found.

Logicians argue that while logical reasoning leads the thinker arrive *certain* conclusions, analogical reasoning provides only *probable* conclusions. Sowa and Majumdar, however, see analogy as a prerequisite for induction, deduction, and abduction, because "in any reasoning about the real world, universal propositions can only be derived by induction, and induction must be guided by the same principles of evidence and relevance used in analogy." [14, p. 19] By finding similarities between a large set of elements on the conceptual level, a conclusion is induced, and that is the process of analogy; for deduction, a new case is evaluated against the given rule, in terms of how the rule applies (i.e., structural matching by analogy) to the case; abduction starts from hypothesizing that a same rule may apply to a small set of elements, and later the rule will be tested and confirmed with a larger set with an induction process. Analogical reasoning is part of other reasoning processes.

Among the four types of reasoning, abduction and analogy have been frequently cited in relation to design creativity. For example, Kolko sees abduction as part of constructive processes such as designing, because a creative solution is generated by finding relationships between seemingly unrelated elements, or redefining the design problem by changing current hypothesis [8]. Gentner et al. emphasizes that, in relation to the process of constructing creative solutions with analogical reasoning, unlike the popular belief of "fuzzy concepts and shifting conceptual boundaries" leading to creative thinking, "creativity is best realized with deeply structured representations that are relatively firm, but that admit limited, structurally guided alterations." [2, p. 34] In other words, a creative idea is born when the thinker has a clear, structured understanding of the current concept, and also is capable of altering the current structure to change the concept itself or the relationship among the elements of the concept.

In this study, the author sees that induction, deduction, abduction and analogy are parts of a continuous thinking process; analogy is at the base of all other processes, induction starts from abduction, and deduction starts with induced rules, so each type of reasoning precedes or follows others, and theoretically all of them are involved in creative processes such as designing, as it will be shown with existing models of the creative design process in the next section.

2.2 Reasoning in the creative design process

In a creative process, such as designing new products or services, a pool of background knowledge is built to (i) understand the current problem situation of involved artifacts, environment, stakeholders and their goals/values in various contexts, (ii) find relevant solutions and technology, and (iii) hypothesize how the solutions might work for the design problem. This study argues creative solutions are constructed by reasoning from this background knowledge. Similar ideas are expressed in the following theories.

Gero and Kannengiesser propose situated function–behaviour–structure (FBS) as a framework to understand a design process where creative ideas are produced. In the framework, a design process is defined as building "connections between the function, behaviour and structure of a design object through experience [. …] the designer ascribes function to behaviour and derives behaviour from structure." [3, p. 374] The linkages between them are built with eight processes: formulation, synthesis, analysis, evaluation, documentation, and reformulation type 1, 2, & 3.

Reasoning is part of all eight processes. For example, *reformulation* type 1 generates creative ideas by reconsidering structure of the object based on the evaluation of structure-derived behavior, and it is understood as *case-based reasoning* [9] or analogical reasoning by Gero and Kannengiesser; it happens when the designer applies their past experiences stored as individual episodes, not generalized rules, to solve current problems. Often they are analogical episodes in different domains, so finding such episodes let designers think what aspects to change from the episodes to apply them to current problems, and the thinking process provides insights for current problems, in understanding/explaining what is yet unknown in terms of what is known.

Howard et al. take the Gero and Kannengiesser's model further [6, p. 168]. In their adapted FBS model, (i) the eight processes categorized into *analysis*, *generation* and *evaluation* processes, and (ii) dotted lines are added to shows how information obtained from the analysis process is continually interpreted and used in generation and evaluation processes. Among Gero and Kannengiesser's original eight processes [3], five are defined as generation type: Formulation, Synthesis, Reformulation type 1, 2, and 3. Howard et al. suggest that three levels of creative outputs are resulting from them: Formulation and Reformulation type 2 lead to new ideas on the behavioural level, Synthesis and Reformulation type 1 lead to new ideas on the structural level, and Reformulation type 3 leads to new ideas on the functional level [6].

In all three types of creative outputs, the designer's reasoning processes are inherent, because the creative outputs result from transformation of given information (i.e., functional, structural, and behavioural variables at hand), according to Michalski's Inferential Theory of Learning [11, p. 13]. In this theory, current knowledge can be transmutated either (i) to generate new knowledge (i.e., changes are made in the content, organization and certainly of current knowledge) by abduction-induction or analogy, or (ii) to simply manipulate and produce derived knowledge (i.e., changes are made only in the organization of current knowledge) by deduction. In this study however, as stated above, analogy is considered part of other reasoning processes that are sequentially connected, so no attempt will be made to identify which type of reasoning leads to which type of knowledge.

For new knowledge generation, in the same paper, Michalski articulates that the thinker's prior knowledge is transmutated with eight binary-pair operations: generalization–specialization, abstraction–concretion, explanation–prediction, similization–dissimilization, selection–generation, agglomeration–decomposition, characterization–discrimination, and association–dissociation. In the next section, how these operations are defined, and how they apply to particular actions/thinking designers and researchers take during the design process will be exemplified with empirical data.

3. How creative ideas are born by reasoning: Michalski's knowledge transmutation operations observed in the service design process

The transmutation operations for new knowledge generation are defined as eight binary pairs, meaning the designer can take either an inductive approach to gain more conceptual nature of knowledge induced from specifics, or take a deductive approach to see how conceptual knowledge applies to specifics. Often, the two directions of approaches are observed together as the thinker re-shapes her ideas in various ways. In this paper, the eight operations will be exemplified with research data collected from a graduate level service design workshop and follow-up interviews. In this five-day workshop, students and two instructors collaborated to improve the sustainability of public services in Helsinki area. Their discussions and final presentations were recorded to capture how students' initial design ideas evolved through the interactions. After the workshop, two students on the same team (P1 and P2, hereafter) worked on a school cafeteria (A-café, hereafter) service re-design project were interviewed, to see how their design solutions can be tied back to information gathered and reasoned during the research phase. The interview questions were designed to guide them analytically reflect on their design rationale, process and outcomes. Each student clarified her school cafeteria experience in general, collected data and insights, relevant experiential and theoretical knowledge, how design problems are framed and solutions are hypothesized, more hypotheses about food sustainability-related issues, and how she evaluates the proposed solutions in light of different theoretical frameworks provided by the interviewer (i.e., the author of this paper).

In the next section, Michalski's eight knowledge transmutation operations will be summarized following his original definitions [11, pp. 19–21], and exemplified with two sets of data (instructor-student conversations during the workshop, and P1 and P2's comments made during the follow-up interviews). As stated above, most operations are all abductive-inductive, deductive, or analogical in terms of reasoning type.

3.1 Generalization–Specialization

With generalization, a description that characterizes a set of elements is applied to a larger set of elements, while in specialization, less elements that fit to the description are found. This process applies when design researchers go out for a field observation of consumer behaviours. Based on what they saw, they define consumer profiles, i.e., different groups of consumers with shared demographic characteristics and similar goals in relation to the service/product developed. Consumer profiles are created by generalizing what the researchers saw from a small number of sample consumers to the whole population. Later, researchers can find sub-segments in each profile, and it is a process of specialization. The following example is P1's comments made during the interview, explaining why pictograms are an effective solution for A-café.

> **Interviewer:** So, if we compare pictogram and text label, for instance, like saying "fish" or "vegetable", is there any group of users who will particularly benefit from pictograms?
>
> **P1:** […] ideally, yes, because it is not always easy to recognize pictures for many people, especially **old people** […] but considering the target group […] the kind of audience that comes there, I think they are... we chose pictograms only because students, first of all, they are **creative students**, it is an art school, so you expect them to be designers, and second, **business people** who are learned, they know, they can associate the pictures immediately, […] it is just the first time they need to look and they learn it.

P1 talks about three groups of A-café customers, design students, old people, and business people. She is a design student, and she *generalizes* her ability to read pictograms to the whole group of design students, that they would also be able to read the pictograms like she does. The A-café customers are divided, i.e., *specialized*, into two groups, student and regular, and within the regular group, she also implicitly separates old people who may have difficulties in reading pictograms, from business people who can learn pictograms immediately. Insights gained from this generalization–specialization processes add new knowledge of who the consumers are, and what their goals and limitations are. Based on such knowledge, designers can define and evaluate their solutions.

3.2 Abstraction–Concretion

Abstraction is a process of reducing details in a description of a set of elements, to make the description higher-level concepts that are applicable to other sets of elements as well. Concretion, on the other hand, increases details about the set. Numerous abstraction examples can be found in a design process: discovering higher-level design principles by looking at many concrete examples creates new knowledge in design; creating a simple pictogram of an entity by abstracting its most essential features reveals what was formerly unnoticed about the entity.

In the following example, in a conversation with the workshop instructor (T1), she reflects on her teaching and grading experience and *abstracts* some key factors i.e., what she is looking for in students' design process and outcomes, expressed in conceptual terms. Then she *concretizes* the concepts with examples with details.

> **T1:** the main thing was the **problem solving** […] if they notice some problems... they need to be able to define what it is […] and you need to do quite a lot of decisions, […] through discussion... so then, [instructors look

> for] **how the teams worked**... how they were organizing the work within the team, and so the work load would be roughly the same for the team members […] and the quality of work they are producing […] visually, visual quality, […] it was a course mainly for graphic design, or [students] were more, many visually oriented people, so […] then the **effectiveness**... when they were framing the problem, […] they need to think about […] if they are spending time wisely or not, […] what is possible to do in this schedule with this team, within this time [… .]

3.3 Similization–Dissimilization

Similization produces new knowledge by finding similarity between one set of elements and another. Dissimilization also produces new knowledge, but by pointing out the lack of similarity between two sets. Similization and dissimilization are observable when one compares multiple entities in terms of the same criteria: among all attributes of the entities, only some attributes are highlighted, then the similarities and differences between the entities are discussed. For example, during the follow-up interview, P1 compared three university cafeteria K, M, and A in terms of food type, food quality, and atmosphere:

> **P1:** […] M-café is very small, but food is sometimes really nice, the salad bar is ok, […] actually compare to K-café, M-café has better salad definitely. K-café is good, because it has vegetarian food and vegan food options, so people can opt for that, and uh... A-café, right now, it is just looks nice, it is beautifully done […], and the space is comfortable, feels very cozy and homely, but the way the food is structured, and the quality of food also, compared to other places, I would not rate it so high. [… at A-café], for students, probably there are only two options to eat, which I do not know why that should be the case... because [K-café and M café] do provide better... with the same cost.

K-café and M-café are *dissimilized* from A-café in terms of food quality, but K-café and M-café are *similarized* in that they have salad bars that are acceptable or better. K-café is dissimilized from the other two because it specializes vegetarian and vegan food. A-café is also dissimilized from the other two, as it provides a better eating atmosphere, but she doubts cost is the main cause of the unsatisfactory food taste at A-café, because food is better at other places with the same cost. Since the project goal is improving A-café service design, through similization–dissimilization operations in this comparison process, P1 gains new knowledge about what are problem areas at A-café, and hypothesizes it can be solved without much additional cost.

3.4 Explanation–Prediction

Explanation generates explanatory knowledge by considering given facts to find the underlying causes and following consequences. Once you understand the relationship, you can make predictions based on the knowledge. Generating new explanations and knowledge starts from abduction where new causal relationships are hypothesized, but the hypotheses are actually predictions made from the thinker's prior knowledge of other causal relationships. Regarding a question during the follow-up interview, P1 provided a guessed explanation.

> **Interviewer:** Scientists recommend [to] cut on meat consumption, [...] only 60g of meat is enough per day, to avoid getting heart-related diseases. [...] A recent study shows most Finns buy food considering health, but they eat meat more than three times a week, that is [probably] more than 60g per day, and they do not wish to change their diets. So how can we explain this phenomenon, people think health is important, but they do not wish to change their diets.

> **P1:** A possible explanation is that either they're continuing this [...] for a very long time, and maybe it is passed on from generation to generation that, ok, eating this kind of food is good for you, and that is how they continue to grow, and there was probably no information [...] saying that oh, now this has changed, this does not exist anymore, so you have to maybe change your diet somewhere… so maybe it is lack of information, and people are still believing that [...] this is how it has to be and how it is going to be. [...] I guessed that because it is something even I face, maybe, because sometimes I do not want to change my food habits, then sometimes people really tell me the reason behind it, why this cannot be eaten so much and why this should be eaten more, even though that does not taste nice, then I feel like oh, maybe I should consider changing my behaviors.

Her *explanation* (lack of information) is made based on her past experience of having changed her mind after being informed, so she recognizes the causal relationship between relevant information and decision-making/behavior change. Based on the knowledge, she *predicts* that providing information may change people's diets, but her prediction is actually expressed in the form of a *guessed cause* that lack of information causes continuation of unsustainable eating habits.

3.5 Selection–Generation

Selection is making a subset from a set of elements, according to some criteria. The opposite is generation of more new elements that also satisfy the criteria.

During the follow-up interview, the author provided Elkington's Triple Bottom Line—people, planet, and profit—as a new theoretical framework of a sustainable business model for P1 [1]. She reflected on her proposed solutions from the framework and began to see how she can make subsets of problem/solutions based on these new criteria, and that was a *selection* process. She found that most of the solutions were created for student customers who are one type of people, but she did not think much about planet or profit even though the project goal was improving the sustainability of the A-café service.

> **Interviewer:** What about planet? So what did you think about the food that they serve?
>
> **P1:** I think the quality of food lacks a little awareness, […] as I said, it will be interesting to see where the actual food is coming from, and why they are serving the kind of bread, for example, […] we saw these days they are serving the red, Bolognese sauce, for example, everything has that in it, so anything that you eat, has that in it, ...and I was wondering why is it like that […] so it will be interesting how much they actually buy stuff ready made, or ... how much they're putting effort to... because we touched upon these issues while we're discussing in the group, as to the timing of serving, because if food has to be ready for so many people, at the same time, so I think their food is going fast, and they are trying to make things really fast, I do not think that should be the reason as to why they're using one kind of sauce. So it will be interesting just.... identifying some of these things, and just go deep into the matter and see what the real reason could be. I don't know maybe interesting data can be found, in terms of environment, how much water they actually use, or then work around structure, that you get better quality of food, timing may be adjusted, and less wastage can be made, or better quality food be served.

With the new framework for thinking, P1 expanded her interests from simple complaints in *people subset* about food taste to *profit* and *planet subsets* of A-café problems: what business or environmental factors are related to the A-café food with a same, red sauce. With new insights, she added more topics for investigation in the profit subset (timing of serving to accommodate as many customers as they can) and planet subset (water use, the ratio of packaged and fresh ingredients) and that is a process of *generation*.

3.6 Agglomeration–Decomposition

Agglomeration is taking elements and group them in to a structure of units, such as building hierarchy, following certain criteria, and the criteria are the conceptual relationships among the elements. The structure built with agglomeration can be decomposed to become a different structure. Agglomeration–decomposition process is often useful in the synthesis phase when designers create clusters of related functions/features, and relate the clusters in a bigger hierarchical structure; for instance, building a hierarchical structure of menus for an website, or creating a function structure for a bike. Agglomeration–decomposition process also apply in the analysis phase when designers try to grasp various problems they found, and decide the priority between them.

For A-café service design improvement, P1 and P2 created a concept map of problems, by *clustering* problems in three big areas, feedback, signage, and paying system, then decided to focus on the signage part because they had only limited time of three days to work on this problem. Then they *decomposed* factors (that are not necessarily causes of problems) that lead to bad customer experiences at A-café: the two different customer groups and meals for each, the space and signage design, and the encounter between customers and service design, such as how people navigate in this space to pick up food. This map is actually a mixture of the problem situation and solution proposals. The confusion between student meal and regular meal was a big problem for student customers, so the team proposes *color codes* that can be consistently apply to menu, food presentation, and signage for easy navigation, while reinforcing menu and food presentation with pictograms.

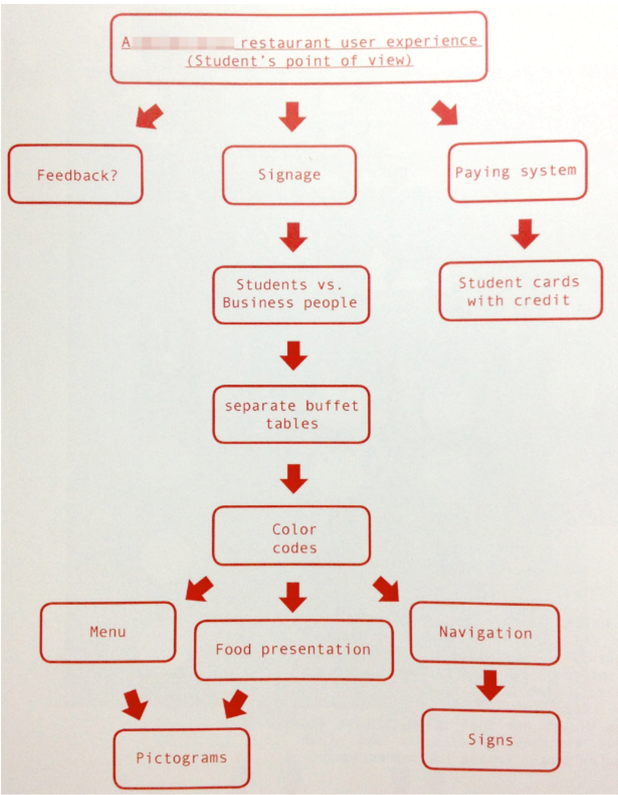

Figure.1 A concept map of problem decomposition in A-café project

3.7 Characterization–Discrimination

Characterization of a class of elements is determining a characteristic description of it, by finding common properties of the elements. Characterization of a class often leads to discrimination, describing how the class is different from other classes. During the follow-up interview, P2, one of the workshop participants from China, characterized Chinese meal and Finnish meal using descriptive words, phrases and specific examples.

> **Interviewer:** …then let's compare Chinese meal and Finnish meal here, so... in general, what is the biggest difference between the two?
>
> **P2:** … in Chinese meal, they are... most of them are warm, [...] our stomach maybe used to it, and we eat rice, and noodles made of wheat, [...] white noodle, [...] and in Finland, I think they do not have their country food, everyone [says] the food culture here is a little weak, ... I heard a lot from other Finnish students, they do not have ... their country style food. [...] and they learned a lot from France, and like the pasta, spaghetti, [...] and pizza, and meat balls from Sweden, and bean soup, ... (that is traditional food) yeah, which is not very popular...

Her *characterization* leads to *discrimination* as well, because there are only two entities discussed here: if Chinese food was characterized as *warm* in general, it implies at least some Finnish food P2 tried was *cold*. If Finnish food culture was considered weak and lacking traditional food, it shows P2 was thinking about the diversity and long history of Chinese cuisine. Her insights gained by characterization–discrimination can be generalized by finding more fitting examples. Later, P2 concluded that food served at A-café was unsatisfactory from a foreign customer point of view, and it was a shared view among international students at the university. P2's reflection partially points to which direction A-café could improve on their menus.

3.8 Association–Dissociation

With association, you can see the logical, causal, or temporal types of dependency between elements based on facts or knowledge, and also you can demonstrate the lack of such dependency between elements with dissociation. During the workshop, two instructors and students discussed features of a smartphone application and what visual style they want to apply to its user interface.

> **Student:** […it is] food journal, so it still reminds you what you eat, but [in a] more relaxed way, 'cause there are a lot of existing apps […] like calorie counter, nutritional facts, [they are] really intense […] because it has to offer you quite exact calories you take, like, if you want to choose egg, you choose if it was large one or small one, is it raw or cooked or how it is cooked, and you have to go through a lot of processes… and you get really stressed about it.
>
> **Instructor 1:** that is stress, really […] I want to have a good life and now […] that is not what good life is, but I like really this drawing as a visualization, maybe it could really have the different look, not […] pictogram of people ... artistic stroke […] to show […] because it is a different thing.
>
> **Instructor 2:** one aspect [to consider is…] mood […] because it was the original idea you had. Maybe […] you can connect that to mood, it is like technical [information] … what are the ingredients and things that you are eating, how that is affecting your mood, and what is the relation there... if you eat like this, did it affect your mood, how was [your] face… [was it] like a big smile, or were you crying…

The application was different from other apps in that it provides more than just calories; it shows how to improve on the user's eating habit for a good life. Instructors suggested a hand-drawing visual style for its user interface. While scientific calorie information is often visualized and thus *associated* with simple and stiff pictograms, this app shows healthy eating in a more naturalistic visual style, based on the conceptual association between nature and health, to reinforce the messages. Association of hand-drawing visual style and rather humane messages also implies *distancing* such a visual style from strictly scientific type of health messages.

4. Reasoning, Design Knowledge, and Design Expertise

The design knowledge generated by reasoning processes *consists of* two types of background knowledge—experiential and theoretical knowledge—as key ingredients, and it *works on* the four areas of designer's expertise to shape and strengthen them. Figure 2 describes the relationship between them as follows:

(1) **On the left-hand side, at the center of the wheel, a designer's experiential and theoretical knowledge grows, complementing each other:** Hahn and Uppa explain that the designer's background knowledge consists of two sides, experiential and theoretical [5]. The experiential side is a collection of knowledge gained by direct-indirect interactions with the natural world. With the experiential knowledge, the designer can recognize both problems to work on and solutions for the problems. The theoretical side of the designer's knowledge is different in that it will let her recognize patterns, structures, and models from what she perceives; she can understand causal and other relationships between entities, construct conceptual models of them, and mentally simulate various solutions while going through the four types of reasoning processes described in this study. In the same paper, Hahn and Uppa emphasizes the *complementary*, not contradictory, nature of these two types of knowledge in that the two sides are "dependent to each other [… ,] what [a designer] knows from her experiential knowledge can be explained with theoretical knowledge, and what she learned as theoretical knowledge will be tested or demonstrated with experiential knowledge." [5, p. 12] Furthermore, with years of experience, the designer's theoretical knowledge will work as if it is part of her experiential knowledge; when she encounters a design problem, she will remember similar cases she solved before and try the same solutions again without consciously thinking about their theoretical bases. Her decisions will look almost *intuitive*, which is how typically experiential knowledge is described.

(2) **At the center of the wheel, the designer's knowledge as a whole is transformed by continuous reasoning processes:** In this study, how the designer's knowledge is developed into creative ideas is conjectured as the results of eight binary pairs of knowledge transmutation operations that change the designer's experiential and theoretical knowledge as pulling forces. Abduction-induction-deduction as a continuous reasoning process are involved in the operations. Analogical reasoning is placed between abduction-induction, induction-deduction, and deduction-abduction because abduction, induction, and deduction processes start from analogical reasoning, and they also transit into others with analogical reasoning. Reasoning, however, is not a purely objective, logical process, when the thinker is a human and she is handling concepts of the natural world; her subjective interpretation of the premises, and what is known about involved concepts from other sources will be mixed in, and she will unwittingly accept them as part of assumptions [7]. Her preferences and depth of knowledge can affect how much weight is given to each piece of evidence. Relying on such flawed but human reasoning processes, a designer can transform her knowledge gained from the problem and solution spaces, to recognize the hidden

relevancy between them, and generate creative solutions. In this study, the cited workshop participants' comments show how knowledge transmutation operations are involved, when they reflect on what they saw as experiential knowledge and what they know as theoretical knowledge, to gain new insights regarding current problems at A-café.

(3) **On the right-hand side, design knowledge is related to four areas of design expertise as two "interlocking and looping processes"**: In Dreyfus and Dreyfus' terms, design expertise is knowing not only "what has to be done", but "how to achieve the goal" as well [4, p. 787]. Hahn and Uppa defined four areas of design expertise: understanding the problem space, representation of current problem, exploring the solution space, and materialization of the solution ideas [5, p. 13]. The four areas are overlapped and structures in a circular manner, to show how the "development in one area can trigger further changes in adjacent areas". For example, from their experience of prototyping and testing solutions for A-café (i.e., building expertise in materialization of the solution ideas), workshop participants P1 and P2 can recognize problems or room for improvement better with other cafeterias (i.e., improved expertise in understanding the problem space), even when consumers are not complaining about them. Design expertise is shaped and strengthened with design knowledge. To create a pleasant dining space, a designer needs to understand how people behave in the space with different goals as a conceptual model in the problem space, or what technology, material, form, structure or function are available in the solution space; based on the knowledge, she defines the tasks in each expertise area, and knows how well the tasks were performed. With more experiences, her performance stabilizes and improves to recognize what others cannot observe, or to devise what others cannot think.

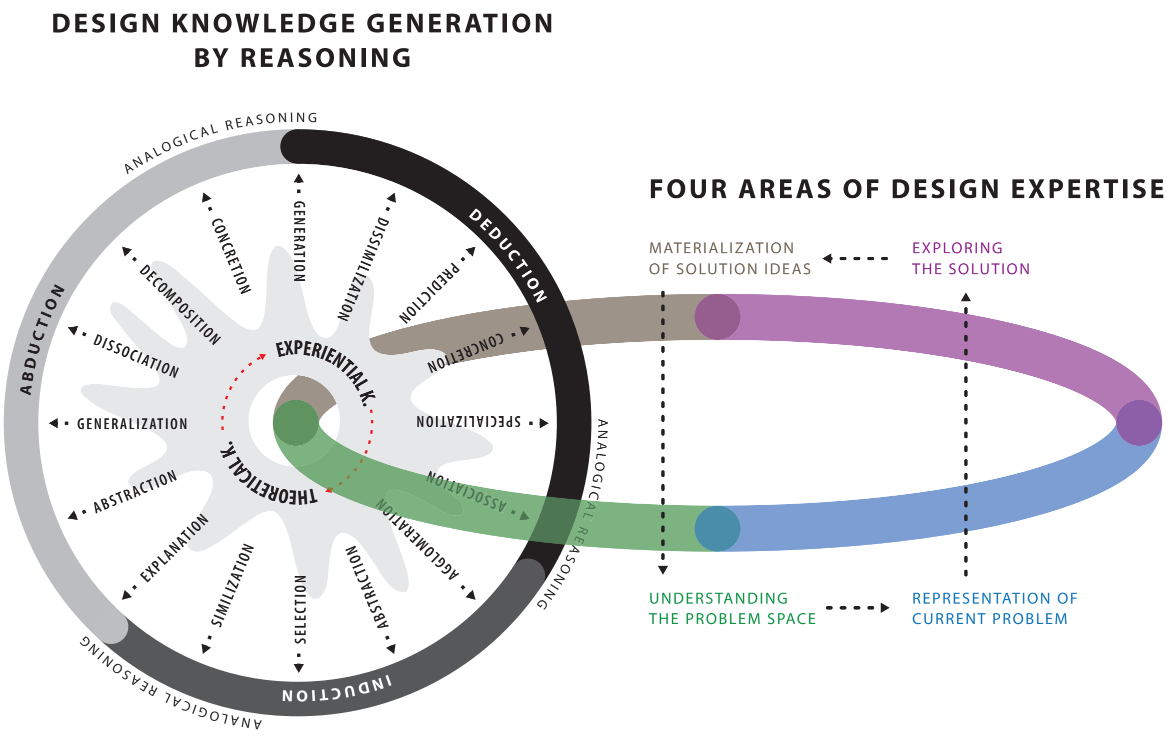

Figure.2 A model of design knowledge generation and design expertise

5. Future Research

In this study, a designer's creativity is described as the ability to transmutate her knowledge—which has experiential and theoretical side—acquired from the current project's problem and solution spaces, until she hypothesizes original connections between them. The knowledge transmutation operations, particularized with empirical examples in this paper, have practical applications as either analytic research methods for the conceptual understanding of situations/entities, or synthetic ideation methods through which design artifacts are constructed.

For future studies, the author speculates that both design praxis and design theory building activities are knowledge generation processes, granting that the nature of knowledge in the two may differ. The knowledge transmutation operations may apply when designers develop solution ideas. Examples of knowledge transmutation in design theory building and design praxis can be compared, along with discussions of different natures of knowledge found in the two, in the future studies.

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