When Engineers from Mars Meet Designers from Venus: Metacognition in Multidisciplinary Practice

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Keyword(s):

Knowledge; intelligence; cognition; multidisciplinary design; software engineering

Abstract:

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ABSTRACT
This study explores challenges of system engineers with respect to the multidisciplinary development of an intelligent document composition system called Probabilistic Document Model (PDM). Implementing intelligent entities that automate human-like decision and performance requires behavior model of subject matter experts (SMEs) whose knowledge could be unfamiliar to system engineers. To include SMEs knowledge in PDM machine learning algorithm, professional graphic designers participate in development by creating templates that demonstrate their design aesthetics on page composition. By comparing such multidisciplinary activity of PDM team (Group 2) and more natural design activity of professional graphic designers in a work setting (Group 1), we examine how successfully PDM algorithm echoes professional graphic designers' knowledge in action. The result revealed that Group 1 designers made the decision through planning, pagination, and evaluation. However, Group 2 designers activity was limited to pagination because their involvement was guided by engineers interpretation on SMEs knowledge. Among 24 design heuristics demonstrated by Group 1 designers, 37.5% were supported by PDM. Some simple heuristics (33.33%) were not included in PDM because engineers did not perceive such heuristics, while other sophisticated heuristics (29.17%) were not implemented due to the difficulty to transfer abstract design concept to explicit code. The loss of such heuristics implies the high cost of communication barrier that engineers need to hurdle in the development of intelligent system.

Author Keywords
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D.2.10 Software Engineering: Design

INTRODUCTION
As the user experience with information and communication technology (ICT) becomes ubiquitous, bridging the gap between disciplines has been gaining attention as a driving force to lead innovation in many fields such as artificial intelligence, experimental psychology, learning science, and healthcare [24]. However, communication between subject matter experts (SMEs) across disciplines is not an easy task. Kazman and colleagues [12] revealed communicative barrier between groups of software engineers and human-computer interaction (HCI) practitioners in an industrial setting. Even though they were co-located at a same work site and co-assigned to a same project, only 50% of software engineers contact HCI practitioners to share knowledge. Even worse, the contact was made after the development is completed (33%) or during development (30%) rather than the early phase of development that requirement and specification are determined (5%). As a result, both software engineers (68%) and HCI practitioners (91%) felt that the design decision was made unilaterally by software engineers.

In developing intelligent system, lack of communication between disciplines could be even more problematic because the system implementation requires reconstruction of human behavior to achieve a goal. Such an artificial embodiment of human-like thinking should be assisted by intelligent system entities that correctly perceive, understand, and manipulate surrounding world [18]. Thus, when implementing intelligent systems that act like relevant SMEs, system engineers should clearly articulate how SMEs think and act.

This study explores challenges of intelligent system design of which the implementation is performed by system engineers, yet the cognitive process of intelligent entities is borrowed from graphic designers. We observe a multidisciplinary design effort of Probabilistic Document Model (PDM) that acquires professional graphic designers' knowledge when building algorithm for automatic document layout. In this paper, firstly, we introduce similar research on document layout system and theoretical foundation with respect to the nature of SMEs' knowledge and metacognition, which is known as *cognition about cognition* or *knowledge about knowledge*. Secondly, we highlight our research questions and hypothesis. Thirdly, we present our study that compares heuristics of document layout design from two groups: professional graphic designers who demonstrate design activity in natural work setting (Group 1); engineers and graphic designers of PDM team whose knowledge is implemented in PDM algorithm (Group 2). We cluster the result to four categories to analyze how PDM team's multidisciplinary design heuristics fulfill Group 1 designers' knowledge with

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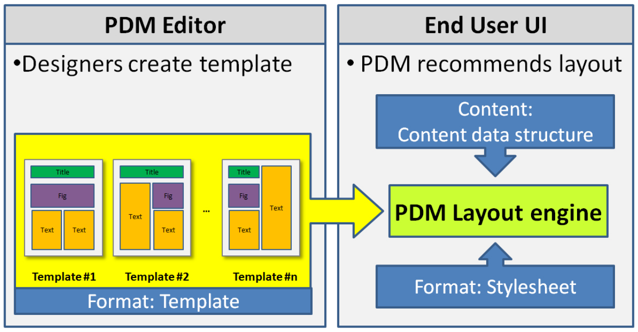

Figure 1. How PDM works

respect to relevant components of metacognition (metacognitive knowledge, awareness, and control). Lastly, we revisit our research questions and hypothesis by arranging our clustered result in metacognitive framework (metacognitive knowledge, awareness, and control).

The contribution of this research is to clarify challenges of intelligent system design of which the behavior simulates SMEs' activities, but the development is directed by system engineers. Assuming that Group 2 engineers would not be familiar with design heuristics of graphic design as well as how to learn such heuristics, the clustered activity of Group 1 would assist engineers in knowing "what SMEs know" beyond "what engineers know about SMEs' knowledge". Although researchers have widely studied intelligent desktop publishing systems [8, 10, 20], most of them explore what they developed (e.g., algorithm, system architecture) rather than how accurately and thoroughly SMEs' knowledge in action is implemented in the system (e.g., decision making process and design rationale of the behavior).

RELATED WORK: INTELLIGENT DOCUMENT LAYOUT

Today's desktop publishing software enables novice users to compose electronic document with minimal training. However, composing aesthetically pleasing document still demands experienced and creative decision making. To assist users with no professional training on publication design, researchers have developed various intelligent systems to simulate design heuristics of SMEs.

Harrington et al. [10] suggests a method to quantify nine conceptual design heuristics: alignment, regularity, uniform separation, balance, white-space fraction, white-space freeflow, proportion, uniformity, and page security scale. According to Harrinton's formula that measure the negative elements that harm heuristics, such conceptual heuristics can be transformed to a number ranging from 0 (bad) to 1 (good). This method suggests a solution to connect conceptual level design aesthetics with quantitative variables.

Unlike Harrington's approach that specifies context independent design heuristics (i.e., Including margin, white space should be about half of the total page area.), GAUDII [8] focuses on obtaining users' intention by asking document properties to initiate document layout: page orientation (landscape or portrait); typography (formal or fancy fonts); color scheme brightness (dark or light). While GAUDII requires manual yet customizable user input to capture user intention, Harrington's approach follows static heuristics to automate decision making with minimal user input.

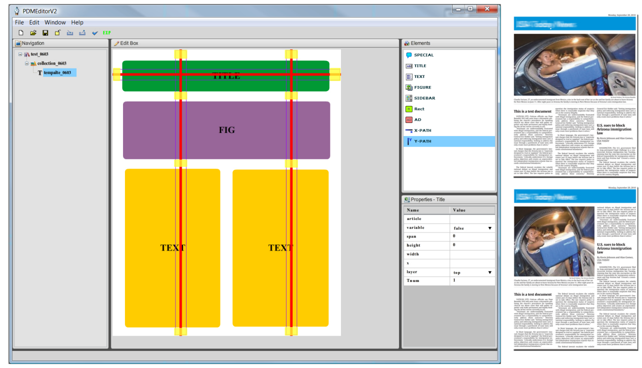

Figure 2. PDM editor (left), Document samples created by PDM (right)

Alternatively, to include more human-like intelligent behavior to the system, Bricolage [13] and PDM [2] capture human behavior in advance by using Bricolage collector and PDM editor, respectively. Bricolage collector captures users' cognitive mapping to perceive page structure of paired web page by region to region such as header, footer, and logo. By obtaining diverse mapping result of regions and relevant rationale, Bricolage utilizes human perceived visual semantic of web pages to automate web page design.

Similar to Bricolage collector that collects human heuristics to train the system, PDM editor acquires professional graphic designers' recommendation of various page compositions to save in abstract form (template). While creating templates by using PDM editor (Figure 2, left), designers perform tasks for pagination and parameterization. Pagination refers to the composition of page elements (text, figure, and text stream) to define relative positioning among elements and parameterization means assignment of allowable range (min, max, and mean of width and height) of page elements and spacing. By learning designers' heuristics on pagination and parameterization in advance, PDM intends to encode SMEs' intuition in visual aesthetics as part of the algorithm.

The template library that reflects behavior model of SMEs is eventually integrates stylesheet and content data structure while the end user composes page with given content (Figure 1). Content data structure specifies logical relationship between text and image. Templates refer to geographical element composition and relevant parameters. Stylesheet determines specification of elements denoted in templates. To compose a document with actual content, PDM calculates probability score of candidate templates by matching given content with template library to suggest the best layout that fits in length (Figure 2, right). Once PDM engine suggests the best layout, the user reviews and modifies the result by personal preference if necessary.

FOUNDATION: KNOWLEDGE AND METACOGNITION

Metacognition is coined by Flavell [7] as one's knowledge that perceives one's thinking process in problem solving and creates strategies based on what one knows and does not know. Baird [1] defined three components of metacognition (knowledge, awareness, and control) that are related with how knowledge exists and how one applies such knowledge in the cognitive process. Metacognitive knowledge refers to the nature and technique of learning that concerns about how people learn. Metacognitive awareness and control refer to the perception of task and decision making process, respectively. System engineers' challenges in modeling SMEs' knowledge can be framed with such metacognitive components: how engineers learn about SMEs knowledge (knowledge), what engineers know and don't know about SMEs knowledge (awareness); and how engineers make a decision to utilize SMEs knowledge (control).

Learning about SMEs' knowledge is difficult because, ironically, SMEs are usually experienced. Unlike novices, experts' experienced knowledge is generally tacit because it is performed unconsciously and automatically in inexpressible manner [3, 15]. Additionally, the failure to perceive or describe behavior could result to underestimation of tacit knowledge [14] that is usually complex and hidden in performance as know-how. Experts know something so well that they are unaware of relevant heuristics that guide their successful action and people are likely to share only explicit knowledge because it is easier than tacit knowledge to explain [5, 16, 22]. Thus, the successful modeling of SMEs knowledge highly depends on engineers' ability to aware and transfer SMEs' tacit knowledge to explicit code.

In additional to the level of expertise, knowledge in creative thinking and action-oriented behavior tends to be more tacit than knowledge in logical thinking [22]. Tacit knowledge, which represent thoughts, intuition, common sense, and work experience, is much more difficult to transfer than explicit knowledge because tacit knowledge can be passed by direct or personal contact and participatory action rather than descriptions and instructions [4, 9, 19, 23].

RESEARCH QUESTION AND HYPOTHESIS

Engineers' approach to acquire SMEs' knowledge may vary. Ideally, engineers who work in frequent and tight interaction with SMEs or learn SMEs knowledge by hands-on experience would have easier acquisition tacit knowledge than engineers who learn SMEs knowledge from explicit yet indirect resources only (e.g., book, lecture, etc). Note that the difficulty of tacit knowledge acquisition often lies in bottleneck in perception and description of knowledge [5, 16, 22], we assume that the successful implementation of SMEs knowledge depends on how SMEs' knowledge exists in engineers' cognition (Figure 3). How well professional graphic designers' tacit knowledge is perceived and understood by system engineers during the multidisciplinary development? What is the main reason that causes failure, if any, to acquire SMEs' knowledge and how can we avoid such failure? The first and second research question explores engineers' *knowledge* and *knowledge about knowledge*, respectively. We hypothesize that knowledge in engineers' cognition (explicit, status 4) is a subset of SMEs' knowledge in action (tacit, status 2) that is likely to be embodied [6].

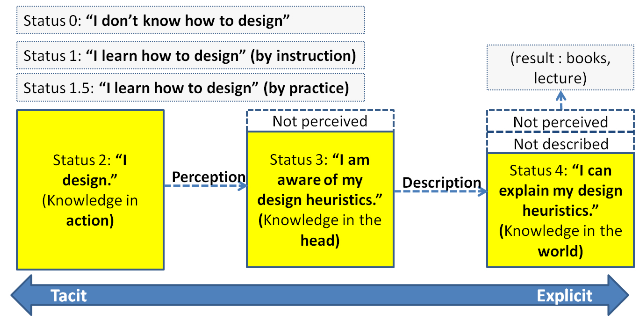

Figure 3. How knowledge exists: In action, in the head, or in the world

STUDY OVERVIEW

The purpose of the study is to observe how knowledge on document layout design is understood and executed by two groups: graphic designers (Group 1) and designers and engineers of PDM team (Group 2). By comparing decision making process, object of interest, and relevant design heuristics, we examine how successfully PDM team (Group 2) implement SMEs' knowledge in the system to simulate document composition task that is equivalent to graphic designers' design activity in a natural setting (Group 1).

Designers and engineers who participate in the study work for a global company in ICT business that provides various printable media (magazine, brochure, newspaper, card, etc.) to individual or organizational customers. Designers are mainly responsible to create promotional, communicative, and commercial document, whereas engineers perform research in printing and imaging technology. Group 1 is composed of four designers (D1 - D4), one (D2) of whom is a member of PDM team. Group 2 is composed of two engineers (E1, E2) and two designers (D2, D5).

To collect data, designers in Group 1 (D1- D4) were asked to simulate document layout design activity by demonstrating the creation of their own work sample from start to end. Designers performed the task on their own office and were encouraged to use their preferred method and resources. Designers' thought process was collected by think aloud protocol. A semi-structured interview was followed after the simulation. The participation time ranged from 60 to 90 minutes. The think aloud procedure and the interview were video-recorded for further analysis.

PDM team was initially identified as one engineer (E1) and one designer (D5). However, while interviewing E1, we found one more engineer (E2) and designer (D2) as additional contributors. E1 and D5 are located on the same work site, whereas E2 and D2 are located remotely. Data collection from Group 2 was performed through four phases of one-on-one interaction (Table 1). Interaction with PDM team members in each phase takes about 60 minutes except Phase3 which is not applicable.

Table 1. Data collection: PDM Team

Phase	Method	Participant
1	Observe demonstration, interview, and obtain resources	E1, D5
2	Review resources and perform additional interview	E1
3	Send e-mail to ask questions	D2
4	Observe demonstration and discuss	E2

Table 2. Definition of terms

Terms	Definition
Document	Type of printed media. (e.g., magazine, newspaper)
Section	Unit of document. (e.g., cover, main article)
Page element	Objects used to compose page(s) (e.g., title, body)
Pagination	Compose page(s) by page elements and parameters
Parameter	Variables to set page composition (e.g., width)
Parameterization	Set parameters (min, max, mean)

In Phase 1, E1 explains the concept of PDM (Figure 1), demonstrates graphical user interface (GUI) of PDM editor (Figure 2, left), and shows output samples (Figure 2, right). The demonstration was observed by note taking followed by a semi-structured interview. After the interview, E1 provides written summary of PDM [2] and relevant resources for further review (executable PDM editor file, xml files for content data structure, template, and stylesheet). Independently, D5 demonstrates the creation of the template file using PDM editor GUI. After the demonstration, a semi-structured interview was followed. Resources obtained from E1 during phase 1 were examined to facilitate the follow-up interview with E1 (Phase 2).

Additionally, D2 and E2 were contacted through e-mail and video conference to report the contribution to PDM development (Phase 3) and demonstrate advanced feature of PDM of which the heuristics are grounded to Harrington's approach [10] (Phase 4). Since the end user UI (Figure 1-right) was not available at the moment, we did not include the relevant interaction in this study.

We select different method in observing each group because of the assumption that the knowledge of Group 1 and Group 2 on document layout would exist differently in our hypothetical framework (Figure 3). The design activity of Group 1 designers is performed by embodied knowledge that is acquired by practice (Status 2 in Figure 3) and can be repeatedly executed in real time. However, in case of Group 2, the design activity of PDM team would be aggregated contribution of each stakeholder whose status of knowledge may vary in Figure 3). Important terms that are frequently referred during the study are defined as Table 2.

RESULT: GROUP 1 (DESIGNERS)

The graphic designers who participated in the study had five years of professional experience in document publishing industry except D4 (fifteen years). Two designers selected graphic-dominant magazine layout design, whereas the rest two chose text-dominant newspaper layout design for demonstration. All designers demonstrated document layout using Adobe InDesign. Optionally, they used pen and paper or Adobe Illustrator to assist advanced design activity.

Each designer's simulation was transcribed and visualized

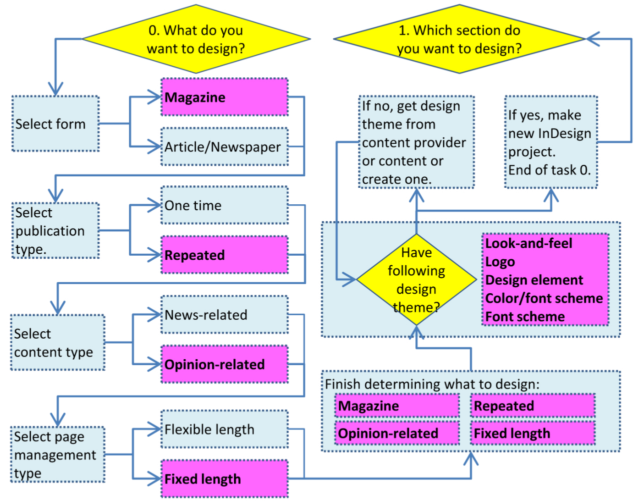

Figure 4. Workflow example of a graphic designer (D3)

in the flow diagram (Figure 4) to specify decision making process, objects of interest that are used to make decisions, and relevant heuristics that represent design rationale. The work flow of four designers were aggregated to find consistent procedural patterns in the overall design activities (Table 3).

Decision making process

Designers' decision making process was observed as three steps (Step 1-3 in Table 3): define the goal and set relevant strategies (planning); compose page with page element by following strategies (pagination); and apply advanced design heuristics to iterate or confirm the design (evaluation).

Step1: Define the goal and relevant strategies (planning)

The main task in this step is to figure out the message that the document aim to convey to the readers through visual communication (Step 1 checklist of Group 1 in Table 3). In this step, designers focus on concerning the whole document from front to end cover rather than individual section. Regardless of the document type (magazine or newspaper), designers initiate the design activity by articulating characteristics of the document. (i.e., What is this newspaper about?, What is the message that this magazine want to tell?, Which look and feel and visual element is better to use to assist visual communication?) All designers report that good design should enable successful visual communication between publisher or writers and readers by appropriately using font, color scheme and white space. D1 defined her graphic design activity as follow.:

"I think good design is a connection between abstract message [from the client] and actual visual output at hand using their contents, design, and their look and feel".

Checklist items in designers' strategy include how to determine visual identity of the document. If available, designers

		Group 1		Group 2		
No.	Step	Checklist	Check point/solution (examples)	PDM element	Decision	Category
1	1	What is the role of section in the document?	headline article OR table of content	n/a	manual	C
2	1	How is the section composed?	Main article OR mix of main and sub article	n/a	manual	C
3	1	What is the section about?	opinion-related OR news-related	n/a	manual	C
4	1	How is the section/document composed?	graphic-heavy OR text-heavy	n/a	manual	C
5	1	What is the look and feel?	crowded look OR modern look OR elegant look	stylesheet	manual	B
6	1	What is the layout strategy?	designed OR templated	n/a	manual	C
7	1	Is the length limited?	yes OR no	n/a	manual	C
8	1	How long is the section/document?	single page OR more than two pages	n/a	manual	C
9	1	What is the publication cycle?	single issue OR weekly OR monthly	n/a	manual	C
10	1	How is the section spread?	left-right spread OR front-back spread	template	auto	A
11	2	How is the page divided?	Column(s) / sidebar / white space	template	auto	A
12	2	How is the content divided?	header / footer / title / body text	template	auto	A
13	2	How is the content presented?	text / photo / line / banner / logo	template	auto	A
14	2	What do you adjust to fit in length?	leading / kerning / width / height	LE	auto	A
15	2	What do you adjust to fit in theme?	font scheme / color scheme	stylesheet	manual	B
16	2	Which elements are used?	basic element / main element / design element	CDS	auto	A
17	2	How do you make current page recognizable?	adjust or integrate text and image	n/a	n/a	D
18	3	Is the visual flow appropriate?	adjust parameters of page element	n/a	n/a	D
19	3	Is the communicative flow appropriate?	adjust parameter and style	n/a	n/a	D
20	3	Is the design consistent as intended?	in page / in section / in document	n/a	n/a	D
21	3	Is the design contrasts as intended?	in presentation of design element	n/a	n/a	D
22	3	Is the page visually direct readers?	no trapped white space	n/a	n/a	D
23	3	Is the section length change by issue?	use side bar in multipurpose use	n/a	n/a	D
24	3	Is the page easy to read?	adjust parameters of page element	LE	auto	A

Table 3. Result: Group 1 and Group 2 (CDS = content data structure, LE = layout engine)

contact creative directors on the customers' side to make decisions. If no creative direction or design theme is available from customers' side, they create the theme by their own decision. Decisions made in this step affect pagination in step 2 and evaluation in step 3. Hence, designers put majority of effort and time to complete tasks in this step to draw an overall picture and assign correct direction.

Step2: Compose page with page elements (pagination)
Using various tools, designers roughly visualize the result of planning (Step1) to prepare for pagination: drawing rough grid-based outline using pen and paper; using supporting user interface of document editing software (e.g., Art Board of Adobe InDesign); or directly divide pages in page editing software. They use grid and note to declare page number, files in use, and location of elements in the grid. D1 defined this process as *"putting all things there what the contents need to be and then going back and tweaking things to make it"*. Details in pagination mostly reflect strategies that are determined in the previous step. For example, D3 includes white space in his design for practical reason as follow.:

"Like this financial article that is published daily, you don't get a good idea of what they're gonna be created in length on a daily basis, so I have this empty white space here in my template to pull out extra such as table when I'm running of my space in the text column."

Sometimes, they open image editing tools (Adobe Illustrator) to create extra images if their target document requires graphically rich element. All designers select Adobe InDesign as their dominant page editing software. After defining rough composition of the whole document, designers step down their focus to section level (e.g., main article) from document level (e.g., magazine or newspaper). The

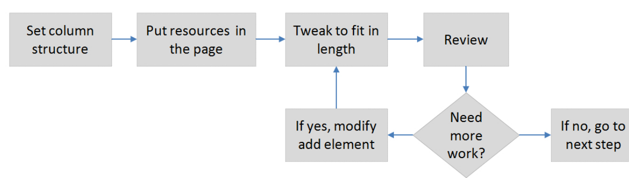

Figure 5. Workflow of step 2 (pagination)

design activity in section level is performed with actual content (Figure 5 and Step 2 checklist of Group 1 in Table 3): import text and photo, move object, modify object to fit in length (resize or crop images, change leading or kerning of text, trim paragraphs), review, and iterate.

When setting page parameters (width and height of column, spacing, page margin) designers rely on the default setup that InDesign suggests unless they have to modify the detail to make the page fit in length. Often, designers want to print document to predict realistic look and feel of the final product that readers will have. Designers sometimes reuse snippet of design elements (e.g., chart area, header block) that were made from previous design if available. Designers use snippet more frequently when they design text-heavy document than graphic-heavy document.

Step3: Assess with relevant heuristics (evaluation)
In this step, unlike pagination in step 2 that reviews the design locally, designers review their design globally. During or after Step 2, designers frequently compare the design of current section at work and other section that they already finalized to ensure whether current design activity satisfies the main goal and strategies that were set in step 1. Relevant heuristics that assist this activity include flow, consistency,

contrast, and balance (Step 3 checklist of Group 1 in Table 3).

Designers highlight that the "flow" of the document supports visual communication and design aesthetics. Designers strategically and situationally apply consistency and contrast in their design rule depending on communicative and aesthetic purpose. For example, consistency is carefully controlled by D2 as follow.:

"We locked out some pieces of detail that we want to be very consistent every day, like the branding that we chose for our newspaper. Also, we always have five articles per page. When you go from one day having four stories on each page to the next day having six on the page, that looks so much different that we want to keep it consistent. Headline always has to be two lines to the consistent look. The flag color for each section is also consistent, like red for US news and blue for sports."

Contrast is mostly highlighted when designing pages with high visibility such as title page of headline article. Designers intentionally break minor rules to address contrast look that eventually makes the page more distinguishable while following basic rule of consistency to ensure unified design concept. D1 specified her strategy on contrast as follow.:

"Having white space makes a larger statement because it makes whatever on the page stronger." " I use this font that I don't use anywhere else in the magazine, which goes against a lot of the rules, but it basically created the balance between the [nearby] image and the title, and makes this article visible."

Designers' heuristics are supported by parameters in two categories: mechanical parameters (e.g., width, height) and semantic parameters (e.g., font scheme, color scheme, visual direction). Mechanical parameters support pagination (e.g., Adjust width and height of page element to fit content in a certain length.), whereas semantic parameters assist communication (e.g., Adjust text and color scheme to visualize appropriate look and feel.). Such parameters interact closely together to ensure careful balance between page elements (i.e., *"I design the text so that it isn't fighting with the image. The color and size of text and image contrasts well."*).

Object of interest and design heuristics

Object of interest is composed of three elements: basic elements for branding purpose, main elements for content visualization, and design elements for aesthetic finish.

Basic elements such as banner or logo are usually given by the content provider and rarely changed. Since these elements are used for branding purpose, designers carefully concern high visibility and coherent look and feel when arranging such elements.

When handling main element such as title, text, and figure in a single section, designers' tends to build holistic strategy within the whole context of document characteristics rather than limiting the focus on the target section only (e.g., I am designing a headline article of a fashion magazine that has a modern look and feel and is published quarterly). Thus, while working with main elements for a single section pagination (step2), detail specifications for such pagination are affected by the characteristics of the whole document (step 1).

Design elements are used for two reasons: adjusting page fit by enabling flexible layout (pagination) and visualizing the message of current section with high aesthetics (communication). When the page has unwanted blank space that needs to be filled, designers modify images first to some extent. If the image modification is unsuccessful, designers add design elements (e.g., line, call-out quote). This approach was especially beneficial when designing a section of which the amount of content varies per issue whereas the page length should be consistent. Similarly, after the basic and main element is added, designers check the characteristics of the page, section, or document and add design element for communicative purpose. D3 performed such extra design to assist better communication as follow.:

"This paint splash image was specially designed for this young and trendy magazine. I added a light paint splash image that follows the color scheme of the page as a background image. It visualizes colorful and fun nature of the story here."

Summary

Designers believed that good design should support successful visual communication. Thus, their perspective broadly ranges across planning, pagination, and evaluation. Such perspective leads them to be concerned with design flow within a whole document even when they focus on page parameters in a single section. Selection of abstract design principles (e.g., balance, contrast) as well as specific parameters (e.g., photo size, font scheme) was determined to support better flow.

RESULT: GROUP 2 (PDM TEAM)

E1, who is a main contributor of PDM development, has experience in industry research about fifteen years. Experience of professional practice of E2, D2, and D5 ranges between three and five years.

Collaboration in PDM team

E1 reported that objects of interest (e.g., title, figure, text stream) and parameter variables (e.g., width and height of white space, image, and text scream) in PDM are selected by his intuition that concerns how easily and efficiently those objects and variables can be encoded to the algorithm. According to E1, his approach aims to fulfill basic design heuristics of layout design (e.g., How to fit content into given pages) rather than advanced design activities.

Additionally, D2 assisted E1 by recommending a book [11] and creating newspaper template to demonstrate a variety of composition (Figure 6). However, the book that D2 recom-

Figure 6. Template samples created by D2

Table 4. A template example that encode page information

FB_T1{top,1}_T2{bottom,1}_T3{bottom,3}_I1{top,123}_I2{bottom,123}
FB: Pages spread front and back (as opposed to left and right)
The page has three articles (T1, T2, T3) and two images (I1, I2)
The page has three columns (123 is the longest composition)
T1{top,1}: T1 starts at the top of the first column.
T2{bottom,1}: T2 starts at the bottom of the first column.
T3{bottom,3}: T3 starts at the bottom of the third column.
I1{top,123}: I1 is located at the top of column 1, 2, and 3
I2{bottom,123}: I2 is located at the bottom of column 1, 2, and 3

mended was not used when E1 built PDM algorithm. According to E1, most books and references on graphic design field usually include high level abstract heuristics. Thus, transferring such abstraction knowledge to algorithm was extremely difficult for E1. On the other hand, transferring design heuristics on document composition from a reference to the system was successful to E2. Unlike the book [11] that is written by a designers and explains designers' heuristics in abstract manners, E2's reference [10], is written by a researcher in the same research community and provides formulas that calculate qualitative design heuristics to numbers.

As a main user of PDM editor, D5's role is to create as many templates as possible to encode professional graphic designers' heuristics of page composition to PDM algorithm. PDM editor enables D5 to drag and drop page element blocks (title, text flow, image, etc.) to the blank canvas to define relative position and fill on the text fields to specify ideal and allowable range of parameters (ideal and allowable min, max, mean space height between page elements).

Object of interests and decision making criteria

E1's object of interest and design heuristics on page layout are observed through two explicit resources: structure of template (Table 4) that is equivalent to labels in PDM GUI and a document that E1 wrote to introduce PDM to research community [2]. In a template file, a single line represents relative positioning of page elements. In addition to template creation, designers create stylesheet which will be eventually coupled with page elements in templates and content data structure. Stylesheet files specify attributes (e.g., font scheme) of content block (e.g., text, images) by types (e.g., head, subhead, list, etc.). Although templates were automatically selected by PDM algorithm to assist page composition, no detail plan or strategies were found with respect to the automatic selection of appropriate stylesheet.

Table 5. Definition of category

Category	definition
A	Supported by PDM automatically
B	Supported by PDM manually
C	Not PDM support, but can be easily applied
D	Not PDM support. Requires professional knowledge

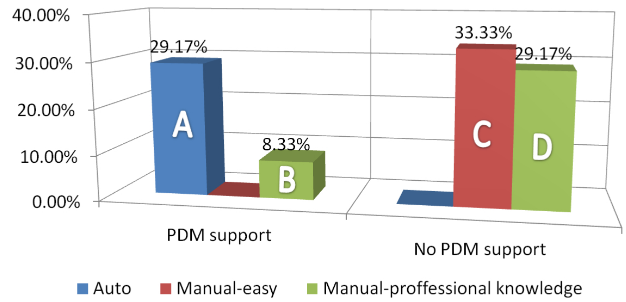

Figure 7. How PDM apply design heuristics (Category A-D of Table 5)

Heuristics that E2 selected from reference [10] (alignment, regularity, uniform separation, balance, white-space fraction, white-space free-flow, proportion, uniformity, and page security scale) addressed higher and conceptual level design aesthetics beyond pagination (e.g., White space should not be trapped.).

Summary

PDM focuses on how to fit given content in length while pleasing design aesthetics. Thus, relative positioning of page elements and parameter specification of elements and spacing were mainly concerned. Reference written by engineers is easier to implement for the system than reference written by designers.

COMPARISON: GROUP 1 AND GROUP 2

Three steps of decision making process (planning, pagination, evaluation) that were observed from Group 1 designers' activity are similar to the three activities of metacognition that monitors one's cognition: planning, regulation, and evaluation. Planning, regulation, and evaluation [17, 21, 25] refer to the identification and selection of appropriate strategies, the comprehension and execution of task performance, and the assessment of performance through revisiting goals, respectively.

To compare design heuristics from designers (Group 1) and PDM team (Group 2), we clustered Group 1 designers' design heuristics into four categories (Table 3, 5, Figure 7) depending on support from PDM (yes, no) and effort to operate heuristics (automatic, manual-easy, manual-difficult). Cluster A and B implies design heuristics that can be demonstrated by PDM either automatically (29.17 %) or manually (8.33 %). Among the heuristics that are not implemented by PDM, cluster C and D specify design heuristics that can be understood without professional knowledge (33.33%) and with some professional knowledge (29.17%), respectively.

Category A and B (Supported by PDM)

PDM supports 37.5% of design heuristics either automatically (Category A: 29.17%) or manually (Category B: 8.33%). Heuristics in category A mostly match with pagination activities, which is equivalent to the Step 2 in Group 1's decision making process (Table 3). This result shows that what E1 stated as low level design heuristics to implement to PDM refer to knowledge for pagination.

As opposed to automated page composition performed by template, determining overall look and feel requires manual stylesheet selection (Category B: 8.33%). Font and color scheme are critical variables that set overall look and feel of the document and eventually facilitate successful communication. For example, D2 who demonstrates newspaper design reported her selection criteria of style with respect to visual communication as follow.:

"Those fonts were picked very specifically to communicate with very classic clean design. Just changing the font can change how it feels even with the same template. For example, if we choose comic sans for the logo, people would not take it very seriously just because of the way that the font looks. They may not know it's comic sans, but it just looks like very childish font, so it wouldn't be a very serious document."

The stylesheet selection is associated with design heuristics that are more sophisticated than simple page composition. The usefulness of the stylesheet to facilitate correct visual communication would be determined by how easily users can select and apply appropriate stylesheet to the design, even with no design experience, rather than how many stylesheet collection that PDM has. Thus, we assume that the appropriate use of stylesheet may not be guaranteed to PDM users unless the usage is automated or at least carefully guided.

Category C and D (Not supported by PDM)

More than half of design heuristics from Group 1 designers (33.33 + 29.17 = 59.5%) were not supported by PDM partially because of lack of communication with designers (Category C: 33.33%) and partially because of the inability to transfer designers' heuristics to algorithm (Category D: 29.17%).

Design heuristics in category C imply that engineers were not aware of designers' concern on planning (step 1) of which the scope ranged document level rather than section level. Since the role of category C heuristics is to set communicative identity of the target document to support further design specification (e.g., "What is the section about?"), the checklist items are simple and highly generalizable. Thus, we assume that these heuristics were missing in PDM behavior model not because those are high level heuristics but because E1 simply failed to perceive designers' broader heuristics as illustrated in our hypothesis (Not perceived knowledge in Status 3 in Figure 8). If E1 had actively communicated with D2 or D5 on the early phase of behavior modeling, most heuristics in this category could have been easily discovered, implemented, and eventually classified as category A or B.

What E1 stated as high level design heuristics are equivalent to those in category D. When explaining evaluation criteria in step 3, designers of Group 1 frequently mentioned abstract terms such as flow, visual direction and energy, harmony, and balance. For example, when arranging text and image side by side in a photographers' magazine example in which photo is the dominant page element, D4 clarified her design rationale focusing on the content-specific restriction as follow.:

"Working with these restrictions really set a lot of design rules. In that scale, the direction, sort of where the photo is going, is another thing that a designer often uses to initially start the layout, like where the photo on the page looks the best, and everything starts from there. The direction of this photo is very much like this [moving hands from left to right]. It's probably subconscious for most people, but it's very much the energy of the image. I think most designers would not want to put the information [text]) over here [left side] because the visual energy moves to the right."

The fact that E1 did now facilitate the book recommended by D2 [11] implies engineers' difficulty to clearly perceive and transfer SMEs' knowledge in their own language (Not perceived and not described knowledge in Status 4 in Figure 8).

DISCUSSION

Components of metacognition

Three components of metacognition (metacignitive knowledge, awareness, and control) [1] and four categories of design heuristics (A-D) that are discovered from the study are arranged in the initial hypothesis (Figure 8). This integration of hypothesis and result identifies how successfully Group 2 engineers transfer SMEs knowledge to PDM system and what is the challenging factor, if any, in the multidisciplinary effort.

Compare to designers who acquire their knowledge from hands-on practice (Metacognitive knowledge: 1D in Figure 8), engineers did not have such experience in design, and even had difficulty in understanding written instruction. Since E1 had difficulty acquiring knowledge from written instruction on graphic design [11], his knowledge of graphic design would be somewhere between Status 0 and 1 (Metacognitive knowledge: 1E in Figure 8).

This difference of engineers and designers on metacognitive knowledge determines the allocation of other components: metacognitive awareness and control. What we observed from Group 1 designers was their knowledge in action (Status 2 of Figure 8) in which the perception of knowledge (metacognitive awareness: 2D) and representation of knowledge (metacognitive control: 3D) cooperated each other in a strategic manner (planning, pagination, and evaluation).

Unlike Group 1 designers, Group 2 engineers' knowledge on graphic design existed through explicit format such as

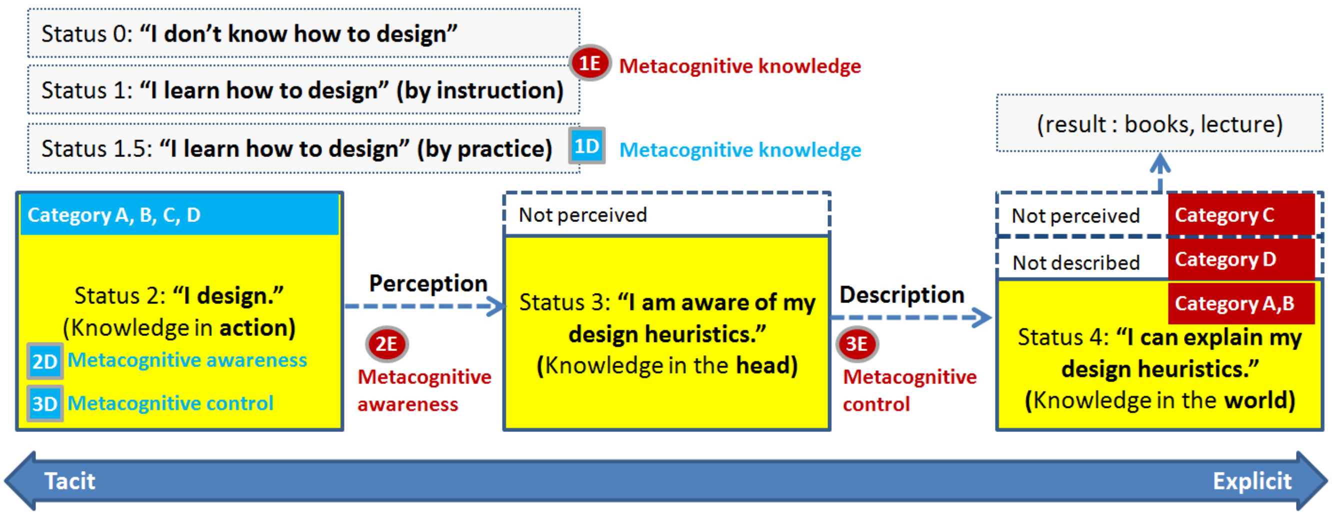

Figure 8. How knowledge exists (Category A-D) by metacognitive knowledge(1), awareness(2), and control(3) of engineers (E) and designers(D)

document [2] and PDM system (Status 4 in Figure 8). The way that engineers' metacognitive awareness (2E) and control (3D) is allocated in Figure 8 while creating PDM algorithm implies engineers' challenges of modeling SMEs' behavior as well as types of knowledge that might be missed. Some simple heuristics (Category C) on planning were not applied to PDM because engineers were not aware of the existence (awareness problem occurred between status 2 and 3 in Figure 8). On the other hand, other heuristics (Category D) were not considered in PDM implementation because the difficulty to encode the concept (control problem occurred between status 3 and 4 in Figure 8).

Move beyond the disciplinary silos

Although Group 2 designers apply significant amount of contribution in creating template and stylesheet, the impact to reflect SMEs' knowledge is relatively limited because their involvement is far from knowledge in action (Status 2 in Figure 8). D5's heuristics that are embedded in PDM would be rather engineers' interpretation of designers' knowledge. Similar to the rare and late involvement of HCI researcher in software engineering process that Kazman discovered [12], the involvement of D5 is made passively only after the algorithm design is completed. Thus, D5's selection of design heuristics was limited by the scenario that is created by engineers' intuition.

In addition, unlike the document written by an engineer [10], the written reference written by a designer [11] was not easily understood by Group 2 engineers. This result implies that engineers may have serious difficulty understanding SMEs' knowledge even though the knowledge is given in explicit format.

Group 1 designers' holistic perspective evaluates both visual and communicative flow of the content within and between sections. This perspective echoes their broad concerns that coordinate overall concept and detail page elements. The fact that designers are aware of the collaborative ecosystem of document publishing (editor, creative director, graphic designers) and sometimes flexibly expanded their role (e.g., creative director) implies that understanding SMEs' work setting dynamics and relevant interactions in the whole ecosystem are essential for engineers to understand SME behavior.

In engineers' standpoint, unfamiliarity and lack of experience on SMEs' abstract and embodied knowledge could be inherent limitation. If engineers performed preliminary communication with designers to observe "what SMEs know", would design heuristics in category B, C, D be successfully encoded to PDM algorithm to be category A? Verifying the benefit of preliminary interaction beyond disciplinary silos in real time system development would be a meaningful future direction. Additionally, note that the number of participants in this study is relatively low, we assume that interacting more designers would help us to collect broad and more generalizable result.

CONCLUSION

The design heuristics of professional graphic designers (Group 1) concern planning, pagination, and evaluation in a consecutive manner which is equivalent to three activities of metacognition (planning, regulation, and evaluation). On the other hand, activity of the PDM team (Group 2) is limited in pagination. Although Group 2 designers' knowledge is included in PDM algorithm through template creation, the contribution is weak because the applied heuristics are far from designers' natural knowledge in action. As shown in the design heuristics clustered in four categories (A-D), PDM acquires designers' knowledge only within the extent that engineers can aware and control. Among 24 design heuristics of Group 1 designers, heuristics in category A (29.17%) and B (8.33%) that are implemented in PDM by Group 2 represent what engineers know about SMEs' knowledge, whereas category C (33.33%) and D (29.17%) that are not implemented in PDM mean what engineers miss during the development due to the difficulty to perceive the existence (metacognitive awareness) and to transfer abstract concept to explicit code (metacognitive control). Thus, by arranging findings through metacognitive framework, this research contributes in articulating how SMEs' knowledge can be underestimated by system engineers and why system engineers should communicate with SMEs, even shortly, to develop robustness system intelligence.

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