Development of a mobile app for generating creative ideas based on exploring designers' on-line resource searching and retrieval behavior

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This study explored the keyword thinking and searching habits of 24 design students and, on the basis of the research outcomes, developed an app for generating creative ideas (AGCI). Thirty practicing designers tested the app, and the retrospective interview results and feedback were used as criteria for modifying the app. This study assigned seven codes to behaviors observed in video recordings of each designer's ideation, and investigated the connections between the seven types of behaviors and the modes of associating words and images to be used as design concepts in developing the AGCI interface prototype. In addition, lateral thinking mode was found related to the designers' idea writing behavior, which could assist them in developing idea sketches further.

Keywords: design cognition, design behavior, ideation, software design

Internet development has resulted in rapidly growing usage rates for tablet PCs and smartphones and has altered communication and thought forms. Because people can communicate with each other by texting on the Internet, they may have developed a different thinking mode. Specifically, the thought process for understanding cognitive schema in language may include a process of read and understanding text messages. Therefore, text plays a vital role in this mode of communicating and thinking, which occurs in interpersonal communication and self-reflection. For example, online keyword searches are performed daily for finding relevant resources or approximate answers. People are stimulated continually by text as they engage in self-dialogue to determine the next keyword. This change in thinking mode occurs not only in daily life but also in designers' ideation. Lang, Dickinson, and Buchal (2001) determined that designers tend to spend considerable time searching for information to resolve design problems. In a study on design behavior, Yen and Cheng (2008) interviewed practicing designers and discovered that they were accustomed to using keywords to search for online resources related to design tasks. The behavior of considering and entering keywords corresponds with the assertion by Segers (2004) that text

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subtly enters ideation early in the design process, enabling memories to emerge and providing visual clues for verbally expressed associations. Text also functions to separate and unify ideas and provides semantic associations that can stimulate designers. As Jonson (2005) asserted, compared with hand-drawn sketches, verbal expression is a major conceptualization instrument at the initial design stages.

Ideation is the process of generating, developing, and communicating abstract, ambiguous, and imprecise ideas; it is indispensable during the design process (Goel, 1995). Words, images, and other symbols are critical triggers that can stimulate thought and association during the design process. In the past, designers depended on written information during ideation. Currently, because of the accessibility of online resource retrieval, designers exhibit the habit of using keywords in searching for resources. Therefore, emphasizing the value of text in the transformation of thinking modes is necessary in research on design cognition.

Numerous scholars in the field of design cognition have investigated the procedures for design reasoning by analyzing the sketching and verbal behaviors of designers according to sketch content development and verbal expression, thus determining the thought patterns of designers during ideation (Goldschmidt, 1991; Schön & Wiggins, 1992; Suwa & Tversky, 1997, 2001; Tang, 2003). Schön and Wiggins (1992) proposed the seeing–moving–seeing model, which explains the repetitive pattern of designers' reception and reaction to visual stimuli during the design process. Schön (1983) contended that designers continually engage in reflection-in-action; in particular, they reflect on their idea sketches, thus facilitating design activities and idea formation. 'Seeing' is a vital impetus for design activities because it triggers reflection. Thus, researchers have typically used idea sketches to explore the creative thinking processes of designers.

The development of the Internet has enabled people to search for knowledge or resources online. The mode of searching and retrieving online resources has altered the reference behaviors of designers, meaning that they are becoming accustomed to referring to and being inspired by online resources. Previous studies have determined that designers' approaches to referencing resources may influence their thinking patterns and idea development (Cheng, 2010; Cheng & Yen, 2008). Moreover, Frey (n.d.) suggested that mobile brainstorming apps enable people to use a recording function to capture unexpected ideas that surface in their free time for creative problem solving. In particular, the light weight of mobile devices increases the likelihood that people want to carry these devices for supporting the creative process. However, design-related studies have rarely addressed topics that are essential to researching and developing design-thinking assistance systems; such topics include whether the mode of online resource referencing exhibits diversified design thinking patterns, exerts various effects on forming design ideas, or becomes a crucial medium for researching design cognition.

Because designers have cultivated the habit of searching with keywords, researchers should consider the relationship between keyword thinking and design idea generation. The behavior of inputting keywords and searching for relevant resources constitutes a part of 'seeing'. However, before deciding on keywords and beginning the search and retrieval process, designers must consider words that are possibly related to the design task. Therefore, previous studies on designers' digitalized search behaviors have asserted that 'thinking' precedes 'seeing' (Cheng, 2010; Cheng & Yen, 2008). Keyword search behavior was found to prompt designers to engage in four modes of association during ideation: word shifting to image association (WIA), word shifting to word association (WWA), image shifting to word association (IWA), and image shifting to image association (IIA).

On the basis of previous studies, this study observed students in design-related fields to examine their ideation at the initial design stages, focusing on the behavior of purposive online resource searching and retrieval and the relationship between the searched online resources and the produced sketches. The stage characteristics of lateral and vertical thinking development were analyzed to understand design thinking patterns. According to the design students' ideation characteristics, behaviors, habits, and requirements, as well as Frey's suggestions, the present study developed a designer requirement-oriented instrument for design idea development: a mobile app that could comprehensively record the formation process of creative design ideas. Subsequently, the designers' use of the app was observed and recorded to evaluate usability. The results can serve as a reference for future modifications of this instrument.

The objectives of this study were to explore design students' keyword thinking, searching habits and searching content, according to the research outcomes, to develop an app for generating creative ideas (AGCI) that designers can use in mobile devices. In particular, this study investigated the relationship between some designers' behavior of writing down ideas (WI) and the higher frequency of their lateral thinking, to emphasize the value of starting the ideation with a mind-mapping process. Finally, design practitioners tested the app, and the feedback was used as criteria for evaluating and modifying the app. The results can serve as a reference for relevant studies on design-thinking assistance systems and can provide researchers in the field of design cognition with a medium and method for recording and observing design thinking patterns.

1 Literature review

1.1 Studies on design cognition

Tan and Melles (2010) adopted an ethnography approach to investigate the design workflow of three graphic designers who had 5–8 years of practical experience. The designers were interviewed before and after a design job to

determine the process of design problem solving according to the framework of activity theory. A repetitive behavioral pattern occurred at the creative activity stage, whereas a linear behavioral pattern occurred during routine activity processes. Stone and Cassidy (2007) conducted an empirical study of 96 media design students at two universities. The students were categorized into two groups: one group used paper-based instruments for sketching, whereas the other group used computer-based instruments. That study aimed to determine whether the two groups of students adopted different synthesis strategies in design thinking. The results showed that paper-based sketching was more effective for producing design solutions and supporting synthesis strategies compared with computer-based sketching. Petre, Sharp, and Johnson (2006) observed the process of knitwear design and used various inspiration sources to investigate the characteristics of visual inspiration use. They identified three strategies used by designers during the design process: selection, adaptation, and transformation. Designers selecting and adapting a particular source or incorporating this interaction into a repertoire can produce unexpected results.

Cardella, Atman, and Adams (2006) analyzed verbal protocols derived from four engineering student designers during the process of designing a playground, showing that hand-drawn sketches facilitated representing, communicating, and design activities. In addition, most students regarded creating and hand-drawn sketching to be major representation activities during the design process, particularly activities that supported the communication of decisions. Jin and Chusilp (2006) explored whether the mental iteration of designers changed according to various design activities. An experiment was conducted on 16 students who were categorized into two groups to perform both creative and routine design tasks. However, Group 2 was required to perform the tasks under limited conditions. All the participants verbalized their thoughts during the design activities, which were recorded for analysis. The results indicated that the students' mental iterations varied substantially according to the various types of design problem and constraint.

To ascertain the characteristics of design activities, Tang (2003) examined the visual reasoning processes of designers and investigated the utility and categorization of design knowledge and its interaction with sketch creation. He observed a strong connection between sketches, perceptions, and functional references; the interaction among the three establishes an entire design process, similar to a visual-reasoning process, through idea sketches. Cheng and Yen (2008) explored how designers stimulated the formation and evolution of ideas through searching and referencing relevant resources. They observed the behaviors of six graphic designers while they performed design tasks, noting that the time spent on searching and referencing accounted for one-third of the entire ideation. This result revealed that reference behavior is indispensable in the design process and should be emphasized in studies on design thinking.

Nagai and Noguchi (2002) empirically investigated how designers think when they use drawing in design objects. In identifying various paths in the thinking process, they determined that these paths possessed a level of abstraction that involved transforming a design goal into a corresponding visual image.

1.2 Studies on the research and development of design-thinking assistance systems

Ozkaya and Akin (2006) proposed a requirement–design coupling approach that is a connection mechanism for requirement-driven design. They modeled a 'continuous and interactive design process for integrating problem formulation and form exploration' to facilitate the architectural design thinking process and enable designers to understand the entire design process, from the initial design stage to the stages of construction and maintenance. Ahmed (2005) enhanced the reuse of design knowledge by developing index knowledge in the field of engineering design. He observed engineering designers and determined that 24% of them spent most of their time acquiring information. Therefore, he asserted that information searches are vital in the design process and developed a method that enabled designers to index design knowledge. Segers, de Vries, and Achten (2005) constructed an idea space system to facilitate architectural design thinking. The designers were inspired by the word–-image connection in the system to think creatively and consider an increased number of perspectives, thus enhancing their work efficiency.

In addition, Siangliulue, Chan, Gajos, and Dow (2015) conducted an online experiment to explore two different mechanisms for delivering examples at the right moment. The results showed that showing examples on-demand assisted people in producing additional novel ideas, leading them to rate highest for novelty. By contrast, ill-timed example delivery might lead to less idea generation. Golembewski and Selby (2010) invented Ideation Decks, a card-based design ideation tool, to support design practitioners in effectively exploring specific problems by aiding in iterative design explorations. When engaging creatively with each Instance Card, the designers critically reflected on the depicted concept in isolation, exploring and gaining insight regarding their internal conceptual models of that instance. In addition, Cruz and Gaudron (2010) described an 'open-ended objects tool' for use in brainstorming workshops; it stimulated the participants to reflect on emotions and desires and to establish a participatory atmosphere among them, thus creating a link between people who were unacquainted with each other. Observing the effect of users' search strategies, Westerman and Kaur (2007) examined the retrieval of inspirational images from computer databases, proposing that creative design tasks require the support of information systems for both convergent and divergent processes.

In contrast to studies that have established design-thinking assistance systems, this study developed an AGCI that focuses on recording word-

thinking processes and paths and enabled designers to open, input, and save sketches repetitively. A record of ideas can be a source of inspiration for further ideation and an instrument for brainstorming, communicating, and sharing in groups, thereby facilitating group discussion, reflection, and feedback. Thus, an AGCI supports the idea development of individual designers and greatly affects idea communication during self-reflection and group brainstorming. The idea space system constructed by Segers et al. (2005) was triggered by designers' written words, thereby limiting the image feedback, narrowing the designers' image reference range, and limiting their image-thinking ability. By contrast, in the present study, the designers could add idea sketches and brief explanations when recording ideas. Thus, an ideation was similar to a design record, in which the words, explanations, sketches, or pictures added by the designer acted as the 'seeing' stimuli or content in the seeing–moving–seeing model proposed by Schön and Wiggins (1992). Consequently, the designers' idea development was not limited to graphic stimuli, and the AGCI could be expanded to aid the designers.

2 Research method

This study observed designers' behaviors of idea generation to research and develop the AGCI. Analyzing the recorded observations facilitated determining and exploring the characteristics of designers' behaviors of idea generation, and the research outcomes were adopted as principles for designing the AGCI. Subsequently, this study developed the AGCI prototype, conducted interviews after the designers used the AGCI, and obtained recommendations for future improvements. The research methods are described in the following sections.

2.1 Observation of designers' idea generation behavior

The designers' idea generation behaviors and processes were observed during the initial design period. Keyword searching behavior and idea generation or shifts in design tasks served as the primary basis for analyzing the designers' idea development.

2.1.1 Observation recording and retrospective protocol analysis

In this study, to derive results that were as objective as possible, design tasks were observed through video recordings, and Camtasia Studio Version 7.0.1 screen-recording software was employed to record the designers' online searches and retrievals. Subsequently, a retrospective interview was conducted with each designer. This method addressed the subjectivity of the analysis by employing objective recording instruments to collect the data. In addition, the analysis results were verified by performing a protocol analysis of the retrospective

interviews. The following paragraphs describe the research participants, design tasks, and data analysis.

2.1.1.1 Observation and recording of the participants. This study purposively selected 24 student participants (14 male and 10 female students, who were invited through a participating associate) who had studied in industrial or media design departments for more than 3 years and continued to study in design-related fields.

The participants individually performed design tasks in a quiet laboratory equipped with a set of office furniture, a PC with Internet access, and two video cameras. The participants were provided with a clean desktop PC, two pencils, and several sheets of paper. The cameras were used to record the ideation; one camera was placed behind and to the right of the designer to record the idea generation behavior, and the other camera was placed in front and to the left of the designer (the location was adjusted according to the participants' handedness) to record the sketching process. In addition, Camtasia Studio Version 7.0.1 screen-recording software was employed to record the designers' working desktop on the provided PC (Figure 1).

2.1.1.2 Design tasks. To ensure a consistent standard for subsequent analysis, all the designers were asked to perform the same design task: to design a logo for a cafe named At Café. Several sheets of A4 paper were provided for the designers to record notes or draw idea sketches during the ideation and were retrieved after the task was finished. In addition, before beginning the task, the participants were provided a task description sheet whose contents were explained by the researchers to ensure that the participants could perform the task. After the participants understood the task, video recording began. The task was performed without a time limit; recording ceased when the participants informed the researcher that they had completed the task. During the design process, the participants were allowed unlimited searching of online resources.

2.1.1.3 Retrospective interviews. To accurately interpret the video content, the researcher conducted unstructured interviews with the individual participants after each one completed the design task, focusing on the idea development process. The interview results were then used to verify the video content.

2.1.1.4 Data analysis. At the data analysis stage, cross-validation was performed for both the data collection methods and data analysts because diverse aspects of the data were used and multiple coders conducted the data analysis. Regarding the observation data, each video was divided by the researcher according to shifts in behavior that occurred in the various segments for each behavior. Three coders classified behaviors in the segments according to the seven behavior codes in the study's coding scheme (Table 1), and any

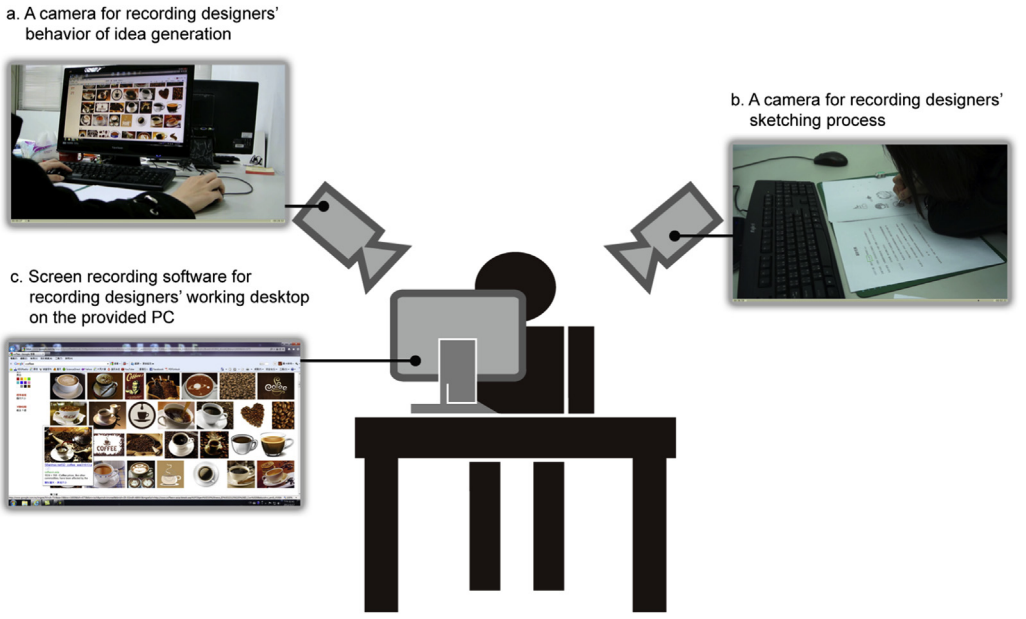


Figure 1 Recording approach used during the observation process

differences in coding results for the segments among the coders were discussed further to determine the final behavior codes. The coding scheme of this study was revised from the coding scheme in Cheng (2010, p. 29–30, Tables 3–2), in which three codes (AT, ROK, and DC) were deleted and two codes (GISR and RI) were revised according to the purpose and methods of this study. The coding scheme was also developed according to the 'synchronizing subject images' and 'processing visual stimuli' for the behavioral structure of activity theory in Kaptelinin (1996).

Specifically, WI represented when the participants developed and recorded ideas with words on the provided A4 paper. RI indicated when the participants entered keywords in search engines to find and retrieve relevant information on the Internet. LRI denoted when the participants browsed through pictures or information without inputting keywords. LOS indicated that the participants looked at the sketches they had drawn. RSD signified that the participants referred to the online information (words or pictures) previously retrieved and saved. CNS and CS concerned the designers' visualization processes and differed regarding whether the sketch a participant was drawing already existed. The behavior code CS was used when the sketch already existed and the participant was revising or adding new ideas. The behavior code CNS was used when the participant was drawing a new sketch.

In addition, when any behavioral segment could not be coded, the three coders were asked to analyze the segment and add another behavior code to the

Table 1 Definitions of the seven behavior codes

Behavior (code)	*Definition*
Writing down ideas (WI)	Writing down keywords as the ideas they generated to be used later; listing, adding or adjusting different alternatives; looking at the written ideas.
Retrieving information (RI)	Retrieving information on-line for capturing ideas, sketching or drawing; saving the retrieved information in the hard disc to be the reference later.
Looking at relevant information (LRI)	Looking at the information they have retrieved on-line in advance. Retrieving action is not included in the behavior.
Looking at own sketches (LOS)	Looking at the sketches they have drawn in advance.
Referring to the saved data (RSD)	Referring to some saved data that have been retrieved on-line by them in advance.
Creating new sketches (CNS)	Creating the new shapes, labels or arrows.
Continuing to sketch (CS)	Continuing to work on a sketch they have drawn

coding scheme. Finally, the internal consistency of the coding among the three coders and the researcher was tested (Figure 2). Moreover, the interview recordings were transcribed and analyzed by the three coders to further confirm the flow of the student designers' behaviors as well as the connection between the stimuli and idea sketches.

2.1.2 Research and development of the AGCI interface

After the analysis process, the designers' design-related thinking patterns and behaviors were integrated, and the results were used to develop an AGCI interface prototype.

2.1.3 Usability interview and modification criteria for the AGCI

At the stage, the designers' operation of the AGCI interface prototype was observed, and the AGCI usability interview results were evaluated to determine whether the AGCI satisfied the designers' requirements and corresponded with the operational behavior. For instance, does the interface of AGCI meet the designers' needs while they are trying to type a keyword in a search engine for retrieving a cafe-like picture? According to the suggestion by Nielson (2012) that 'usability' refers to methods for improving ease-of-use during design, the interview results in this study were used as criteria for improving and modifying the AGCI interface prototype. The usability interviews and procedures are described as follows:

(a) Participants: The study recruited 30 design practitioners (17 male and 13 female students), who had more than 2 years of design work experience and continued to work in a design-related field. The designers were asked to remain in a designated meeting room and were provided with a tablet

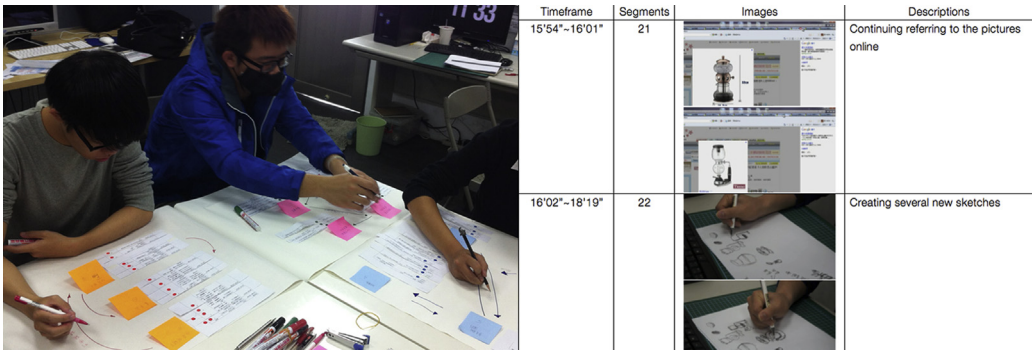


Figure 2 Coding performed by the three coders. (Left picture: The coding process; Right picture: A coding sample derived from the video of Participant H)

(iPad; Apple, Cupertino, CA, USA) loaded with an AGCI prototype to enable them to interact with the interface independently.

(b) Procedure: To experience the three core functions of the interface (Table 8), the designers were required to operate the AGCI; the interviews were then conducted with the designers to understand more clearly their appraisals of the AGCI and use-related problems. Modifications to the interface prototype were recommended according to the interview results.

(c) Three core functions: To investigate the usability of the AGCI, three core functions were derived from the analysis of the designers' behaviors and characteristics: an idea development function, an image search function, and a sketch function.

(d) Data analysis: The researcher and the three coders obtained and analyzed the designers' interview results after the designers operated the AGCI interface and the retrospective interviews were completed. This study focused on understanding the problems that the participants' experienced in operating the prototype for identifying negative aspects of the AGCI. Thus, the participant interview summaries confirmed that particular aspects of the AGCI prototype inconvenienced the study participants; these outcomes were used as a basis for further modifying the prototype interface.

3 *Results and discussions*

This study observed designers' idea generation behaviors and developed and tested the usability of the proposed AGCI. This section presents various aspects of the results: the coding and analysis of the video segments of the designers' behaviors, the order of behaviors during the ideation and connections between them, lateral thinking demonstrated in the idea sketches, design concepts for the AGCI interface prototype, and the usability interview for the AGCI interface.

3.1 Coding and analysis of video segments of the designers' behaviors in ideation

According to the analysis results, the videos of the 24 participants were divided into 458 segments, comprising seven behavior codes (defined in Table 1): WI (writing down ideas), RI (retrieving information), LRI (looking at relevant information), LOS (looking at own sketches), RSD (referring to the saved data), CNS (creating new sketches), and CS (continuing to sketch). The analysis showed that the 458 behavior segments in the observation data could be coded using the seven behavior codes. The Cohen's kappa value for the three coders' intercoder reliability was 0.86.

Table 2 displays the categorization and the presenting frequency of the 458 video segments based on the behavior codes. Each participant had an average of 19 segments (mean = 19.08, standard deviation = 9.48). Participant U had 44 segments (the most), and Participant E had only seven segments (the least).

Regarding the video segments of the behaviors, the frequency of LRI (looking at relevant information) was 179, accounting for 39.1% of the total behavior segments; it had the largest proportion, followed by CNS (creating new sketches, frequency = 124, 27.1%) and RI (retrieving information, frequency = 82, 17.9%). The least frequently exhibited behaviors were RSD (referring to the saved data, frequency = 4) and LOS (looking at own sketches, frequency = 7), accounting for only 0.9% and 1.5%, respectively, of the total behavior segments. Moreover, the LRI and RI totals that concerned search, retrieval, and referencing together accounted for 57% of the total behavior segments; this percentage was higher than the proportion of CNS and CS totals (36.5%) that concerned visual behavior. This implied that the proportion of reference behavior accounted for more than half of the ideation and substantially exceeded the proportion of sketching behavior, which was one-third of the ideation.

3.2 Designers' behavioral order and connection during the ideation

The behavior segments of all the participants were analyzed according to behavioral order. For example, Participant A's first behavior was RI (retrieving information), followed by LRI (looking at relevant information), CNS (creating new sketches), LRI, CS (continuing to sketch), CNS, RI, CNS, LRI, CNS, and CS (Participant A's 11 behavior segments). Based on the behavioral order analysis, all the participants' first behavior was RI (retrieving information), except for Participants B and G, whose first behavior was CNS (creating new sketches), and Participants H and V, whose first behavior was WI (writing down ideas). This revealed that most of the participants, after understanding the design task, immediately entered keywords into online search engines to retrieve information relevant to the task. Only

Table 2 Categorization of the video segments that recorded idea generation behavior

	WI	*RI*	*LRI*	*LOS*	*RSD*	*CNS*	*CS*	*Total*
A		2	3			4	2	11
B		1	1	2		2	3	9
C		2	3			4	1	10
D	1	3	5			4	1	14
E		2	3			2		7
F		5	8		1	2	4	20
G		4	13			8	4	29
H	2	8	11			7	1	29
I		1	4			3	2	10
J		2	3			3		8
K		2	10			8	1	21
L		4	15	1		10	1	31
M		3	6			4		13
N		2	9			5	4	20
O		6	9			6		21
P		3	5			3	3	14
Q		3	6			3	2	14
R		5	8			3	1	17
S		3	5	1		4	1	14
T		5	15	1		8	6	35
U	3	7	17	2		14	1	44
V	10	5	5			9		29
W	3	3	7			5		18
X		1	8		3	3	5	20
Frq.	19	82	179	7	4	124	43	458
%	4.1	17.9	39.1	1.5	0.9	27.1	9.4	

Participants B and G drew sketches at the beginning of idea generation, and Participants H and V began by writing keywords on the paper.

The behavioral order of all the participants was subsequently converted into a connection matrix (Table 3). The vertical axis comprised the behaviors that appeared first in the relationship of behavioral connection, and the horizontal axis consisted of the behaviors that appeared subsequently. The numbers in the matrix show the connection frequency for two behaviors. For example, the connection frequency at the intersection of the first row and the second column is 4, indicating that RI (retrieving information) occurred four times immediately after WI (writing down ideas). By comparison, the connection frequency at the intersection of the second row and the first column is 1, indicating that WI occurred once immediately after RI.

As shown in Table 3, the strongest behavioral connection was LRI (looking at relevant information) → CNS (creating new sketches), which occurred 97 times, followed by CNS → LRI (76 times), RI (retrieving information) → LRI (75 times), LRI → RI (43 times), LRI → CS (continuing to sketch) (30 times), CS → LRI (22 times), CNS → RI (15 times), WI (writing down ideas) → CNS (15 times), and CNS → WI (13 times). Thus, LRI and CNS

Table 3 Connection matrix for the seven behavior codes

	WI	*RI*	*LRI*	*LOS*	*RSD*	*CNS*	*CS*
WI		4	3			15	1
RI	1		75			7	1
LRI	4	43		2	3	97	30
LOS			2				3
RSD			1				3
CNS	13	15	76	3			6
CS	1	2	22		1	4	

were most strongly related, with LRI preceding CNS most frequently in the behavioral order. LRI and RI were also closely related; the behavior in which a designer retrieved online information (RI) and then looked at relevant information (LRI) was robust. The connection between LRI and CS was less strong; the behavioral order in which LRI preceded CS was more frequent than the reverse order. The connection between WI and CNS was weaker than those previously discussed. The designers wrote down ideas (WI) and then drew a new sketch (CNS) more frequently than they followed a sketch with writing.

Moreover, the matrix shows that LRI (looking at relevant information) was strongly related to other behaviors. Specifically, during the ideation, LRI was frequently connected with CNS (creating new sketches), RI (retrieving information), and CS (continuing to sketch). In addition to LRI, CNS was connected closely to other behaviors.

The behavioral connections were also categorized into four association modes that have been proposed in previous studies (Cheng, 2010; Cheng & Yen, 2008); the three coders based each determination on the type of stimulus and whether the outcome of each behavioral connection was a word or an image. Because LRI involved both text and image references, the following three behavioral connections were simultaneously categorized into two association modes: LRI (looking at relevant information) → CNS (creating new sketches), LRI → RI (retrieving information), and LRI → CS (continuing to sketch). When a participant referred to text, a behavioral connection such as LRI → CNS was categorized into the WIA mode (word shifting to image association); in other words, the designer demonstrated an image association stimulated by words. LRI → RI and LRI → CS were also categorized into two association modes for the same reason (Table 4).

The nine behavioral connections that appeared most frequently during the ideation were primarily categorized into WIA (word shifting to image association) and IIA (image shifting to image association), indicating that the designers adopted the association modes of WIA and IIA more frequently

than they did IWA (image shifting to word association). WWA (word shifting to word association) was least frequently used.

3.3 Lateral thinking demonstrated in idea sketches

Lateral thinking is closely related to creativity and pertains to generating new ideas; it leads to changes in attitude and approach and has been proposed to be useful in problem solving (De Bono, 1970). Therefore, the three coders of this study traced each participant's sketching sequence and reference content by examining his or her video data. The analysis of Participant H's sketches is provided as an example in Table 5a. The numbers and arrows in Table 5a denote the participant's sketching sequence during the ideation; serving as a reference for the coders, the four pictures shown in Table 5a were the online images retrieved by the participant and captured by the video recording.

Subsequently, the researcher and the three coders counted the number of each participant's sketches during the entire ideation (Table 6, second row) and grouped his or her sketches into different categories by discussing and identifying the main idea among the sketches for each category, which were also compared with the participant's reference image (Table 5b). The core concept of the categorization process incorporated De Bono's lateral thinking by determining whether the participants' ideation generated new ideas. The categorization of Participant U's sketches in Table 5b (used as an example because of space limitations) shows that Participant U's sketches were divided into four categories: coffee cup, figure, letters, and coffee cup with letters. Finally, this study grouped the sketches produced by the 24 participants during the ideation into several categories (Table 6).

Table 6 shows that Participant V's idea sketches involved six categories of lateral thinking, meaning that Participant V had the most categories of idea sketches among all the participants. The sketches drawn by Participants D and H covered five categories of lateral thinking, and those of Participants N, U, and W encompassed four categories of lateral thinking. The idea sketches of the other participants generally covered one to three categories of lateral thinking. However, all the idea generation processes of Participants D, H, U, V, and W involved WI behavior, thus representing idea development in the mind-mapping process that may have enabled the participants to consider and structure a problem (Table 5a, upper left corner). Moreover, the results showed that the five participants who demonstrated WI behavior and additional categories of lateral thinking were also those among all the participants who performed a greater number of idea sketches (Table 6, second row). Therefore, WI behavior was related to the participants' lateral thinking in performing idea sketches. In other words, WI behavior (writing down ideas) during the ideation may have inspired their lateral thinking and facilitated idea development.

Table 4 Categorization of the nine behavioral connections into four idea-association modes

Idea association mode	*Definition*	*Behavioral connection*
WWA	Word shifting to word association	LRI→RI
WIA	Word shifting to image association	LRI→CNS, RI→LRI, LRI→CS, WI→CNS
IWA	Image shifting to word association	LRI→RI, CNS→RI, CNS→WI
IIA	Image shifting to image association	LRI→CNS, CNS→LRI, LRI→CS, CS→LRI

3.4 Designers' actions influenced by inspirational resources

To investigate how the information may have inspired the participants and led to particular actions, this study extracted the input keywords, which the participants used to retrieve online resources, from the video data and recorded the written ideas that the participants wrote on their papers during the ideation (Table 7). The result shows that 14 out of 24 participants keyed in 'cafe' or 'coffee shop' to retrieve relevant information from online resources. These were the most frequently used keywords, followed by 'cafe logo' (keyed by 12 participants) and 'coffee' and 'cup' or 'coffee cup' (keyed by seven participants).

By comparing the participants' idea sketches with their input keywords, this study discovered two critical and instructive features regarding their sketches. First, most of the student designers who referred to online resources for the keyword 'cafe logo' focused on typography as they sketched (Figure 3a). Second, most of the student designers who referred to online resources related to the keyword 'coffee cup' or 'cup' devoted considerable time drawing the shapes of coffee cups as they sketched (Figure 3b).

In addition, further review of the participants' idea sketches and the inspirational resources determined that the thinking mode of the student designers

Table 5 Analysis and categorization of the sketches

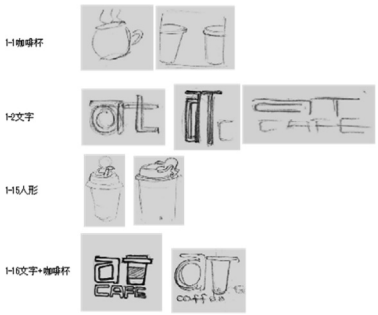
a. Participant H's sketch content, reference content, and sketching sequence	*b. The categorization of Participant U's sketches*
	

Table 6 Number and categorization of the idea sketches of all the participants

Participant	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	*S*	*T*	*U*	*V*	*W*	*X*
Number	6	5	3	14	2	5	7	11	4	3	5	7	3	5	6	6	3	4	4	4	12	9	10	1
Categories	3	2	2	5	1	3	3	5	3	1	2	3	2	4	3	2	2	2	1	2	4	6	4	1

with WI behavior (writing down ideas) in ideation was different from those without WI behaviors. Figures 4 and 5 presents comparisons of the idea sketch analyses for Participants H (with WI behavior) and T (without WI behavior) as an example. During the ideation, the designers with WI behavior first wrote several potential ideas on paper and might therefore have considered keywords for retrieving online resources. Figure 4 indicates that the designers were inspired by referenced images and developed ideas that combined the distinct stimuli. For instance, the designers may have combined Stimulus 1 and Stimulus 3 to form Idea Sketch 1−1 and combined Stimulus 3 and Stimulus 4 to form Idea Sketch 1−3. The designers with WI behaviors tended to extract specific features from different stimuli in the references to use as elements, which they subsequently combined to form divergent idea sketches. In other words, the designers with WI behaviors demonstrated a primarily 'lateral thinking' process during the ideation.

By contrast, the designers without WI behaviors during the ideation started by thinking of a keyword to key into a search engine to retrieve online resources. Figure 5 shows that the designers without WI behaviors continually revised previous idea sketches in preparing their final work. For example, the designers might have drawn Idea Sketch 1−1 by referring to Stimulus 1 and then added Stimulus 2 to Idea Sketch 1−1 in forming Idea Sketch 1−2, followed by revising part of Idea Sketch 1−2 and adding Stimulus 3 to form Idea Sketch 1−3. We speculated that the designers without WI behaviors might have sought online stimuli to concentrate their ideas, continually revising previous idea sketches in preparing their final work. Therefore, the idea existing in the designer's mind may have led to the development of several similar idea sketches. Using this perspective, we concluded that they tended to develop ideas vertically, demonstrating a primarily vertical thinking process during the ideation.

3.5 Design concepts for the AGCI interface prototype

The development of the AGCI was primarily based on the connections that occurred between designers' behaviors during the ideation. In addition, the behavior of resource searching and referencing was used as a main concept. Table 8 shows the constructed AGCI interface prototype. The AGCI design incorporated the following three main concepts:

(a) A mind-mapping function involving words was included on the main screen of the AGCI to facilitate word association by designers.

Table 7 Each participant's inputted keywords and written keywords

Participant	*Inputted keywords*	*Written ideas*
A	Café logo, latte art	
B	Café logo	
C	Café logo, smoke	
D	Cup, cube sugar, stirrer	Coffee, cup, liquid, tableware, cube sugar, coffee cream, coffee bean, smell good
E	Café, coffee cups	
F	Strange, coffee, colorful, cup, brown	
G	Café, coffee design, coffee shop, coffee menu	
H	Categories of coffee, coffee beans, baking process, coffee maker, distilled coffee, coffee filter paper, latte art, coffee lab, café logo	Latte art, beans, taste good, Starbucks, distillation, filter paper, baking
I	Café, café logo	
J	Antique chair, antique chair café, coffee chair	
K	Coffee, Café, At	
L	Coffee, Café, Mélange Café, café logo	
M	Café, café ballet, typography	
N	Coffee shop, café, café logo	
O	Café, steam coffee, café logo, coffee Beans, coffee trees, latte art	
P	Café, coffee cups	
Q	Café logo, coffee, house	
R	Coffee, logo, Café, coffee shop, town	
S	At, café logo	
T	Café logo, cup, e logo, f logo	
U	Logo design, café logo design, coffee store, coffee shop mark, coffee shop, unique coffee shop, logo wall paper, logo, coffee cup, white little man, the action of crawling into a bucket, climbing, actions of white little man	Coffee shop, relax, warm, slow, smell, easy, people, color, brown, green, yellow, coffee company
V	Drinking coffee, smoke, coffee beans, café, in café	At, coffee, beans, at a coffee shop, drink, cup, smoke, in, at, read, drink + beans, smoke + cup, cup + coffee, in café, coffee milk + read, read + mind + beans, coffee + drink + smoke
W	Coffee, coffee shop, coffee beans	Café, nest, cup, coffee beans, smoke
X	Coffee shop, coffee cup, coffee	

The idea association demonstrated by some of the designers at the beginning of the idea generation process was similar to mind mapping (such as Participant H's development of ideas in words, as shown in the upper left corner of Table 5a). Although the association behavior accounted for only a small portion of the entire process, it clearly demonstrates the designer's verbal thinking process and has the same significance as text does at the initial design

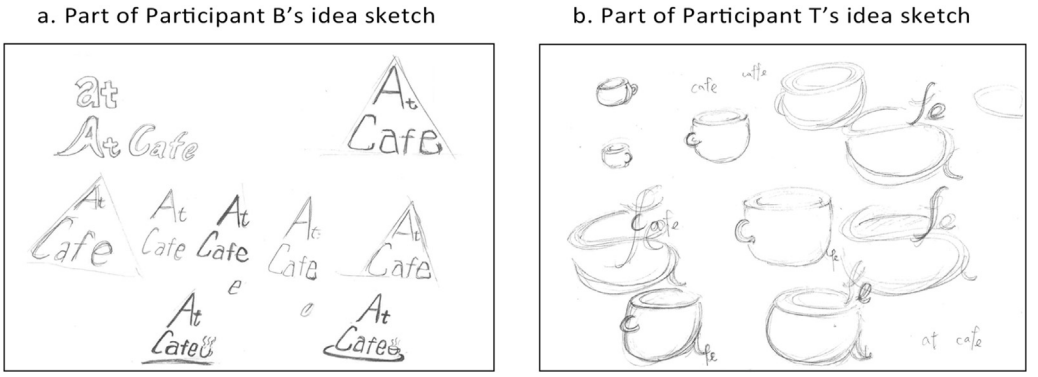


Figure 3 Two examples of the participants who retrieving on-line data by using the keywords 'cafe logo' and 'cup'

Figure 4 Analysis of Participant H's idea sketches (with WI behavior). S, stimulus; I, idea sketch

stage mentioned by Segers (2004). Specifically, text played the role of recording and manifesting the content of the design thinking, and the written words acted as visual clues for generating ideas. Goldschmidt and Sever (2011) determined that design results produced through text stimulation were highly original. Thus, stimulation by text and textual associations are integral to the design process. Verbal thinking (i.e., thinking in words) can effectively facilitate conceptualizing creative space when designers encounter a design problem. In addition, verbal thinking enables designers to record ideas and serves as an inspiration source in exploring other design possibilities.

Figure 5 Analysis of Participant T's idea sketches (without WI behavior). S, stimulus I, idea sketch

Moreover, the analysis of idea sketch categorization and the behaviors of the participants showed that WI (writing down ideas) could facilitate lateral thinking for developing idea sketches (Section 3.3). Therefore, a mind-mapping function involving words was located on the main screen of the AGCI (Table 8a) to facilitate word association, thus enabling designers to structure design problems and solutions and consider all possible design strategies.

(b) A search engine was incorporated into the AGCI system to enable designers to enter keywords into the search engine and retrieve online inspiration.

Except for one participant who accessed textual information during the keyword search process, the participants changed the setting of the search engine to an image search. Hence, after entering keywords in the search engine, they browsed through copious image resources, which served as sources of design inspiration. The idea transformation involved in this behavior is analogous to the WIA (word shifting to image association) mode proposed by Cheng (2010) and Cheng and Yen (2008). During the search process, the designers thought in words but were stimulated by the images in the search results, demonstrating the argument of Do and Gross (1995) that visual analogies are crucial problem-solving strategies for humans. Some designers saved relevant images for subsequent reference. As discussed, the behaviors that were strongly connected during the ideation were mostly categorized into WIA; the design thinking of the designers who adopted the WIA mode involved verbal and visual thinking. This verified the importance of design solutions simultaneously presenting words and images (Ozkaya & Akin, 2006). Consequently, a search engine function was incorporated into the AGCI system (i.e., image search function in Table 8b) to enable designers to enter keywords into the search engine, set the search condition to an image search, and save the desired images to the AGCI.

(c) A sketchpad was incorporated into the idea generation space of the AGCI, enabling designers to reflect on their sketches in producing additional ideas.

During the sketching process, in addition to searching for relevant information by using a search engine, the participants also recorded ideas or sketched on paper after being inspired by the retrieved information. Although the unfinished sketches were not necessarily revised into final design sketches, most of the designers were influenced by these initial sketches and produced temporary design results. At this stage, the designers mostly focused on visual thinking that was similar to the seeing–moving–seeing model proposed by Schön and Wiggins (1992), who explained the continual reception of and reaction to visual stimuli during the design process. In addition, as the designers continually performed reflection-in-action, particularly reflecting on their idea sketches, design ideas were gradually formed (Schön, 1983). Most scholars researching design cognition have observed that the design thinking process is based on the sketch development process (Cross, 1999; Christiaans, 1992; Do & Gross, 1997; Dorst, 1997; Petre et al., 2006; Schön, 1983; Smith & Gero, 2005; Tversky, 1999). Furthermore, the idea transformation involved in this behavior segment is analogous to the IIA (image shifting to image association) mode proposed by Cheng (2010) and Cheng and Yen (2008). Thus, to fulfill the requirements of the designers, a sketchpad was incorporated into the idea generation space in the AGCI (i.e., sketch function in Table 8c). When the designers were stimulated by an image, they could produce relevant sketches. This function enabled the designers to reflect on their ideas and sketches and to record the design thinking process.

The three mentioned design concepts were the main results obtained from observing the order in which designers alternated among searching for pictures, recording new ideas, and sketching in ideation. On the basis of the results, the main AGCI functions were developed and closely related to the behavior of searching for resources during the ideation. A previous study modified the seeing–moving–seeing framework proposed by Schön and Wiggins (1992) to 'thinking–seeing–moving' (Figure 6) to describe the behavioral patterns of idea generation in a digital era (Cheng, 2010, p. 84). This framework explains that, when searching for online resources, designers must initially consider the resources that they require and the keywords that they should enter to find appropriate stimuli. Therefore, they can retrieve potential sources of inspiration from the high number of online resources, which were unavailable to previous designers (who used reference books for inspiration). The framework can also serve as the focus of future studies on support systems for idea development.

This study determined that the three core functions of the AGCI corresponded with the behavioral patterns of the thinking–seeing–moving model and the

required resource references during the ideation (Figure 7). Specifically, the mind-mapping function for idea development satisfied the designers' requirements during design thinking; the search engine function, which incorporated an image search, fulfilled the requirement for image stimulation and reference; and the sketchpad function satisfied the designers' requirements during the design process. The function interfaces in the AGCI were interconnected, thereby facilitating iterative and repetitive behavioral patterns during the ideation.

3.6 Usability interview for the AGCI interface

This study conducted interviews with 30 participants who were invited to experience the three core functions of the AGCI interface. The researcher and the three coders transcribed the interview recordings of the 30 participants. Problems regarding interface use mentioned by the participants were summarized and divided into several problem categories. Subsequently, the interface icons related to the problems were identified, and modifications to the AGCI prototype were suggested. For brevity, Table 9 displays only excerpts from the interview transcripts as examples.

The results of the retrospective protocol analysis revealed that the designers found the AGCI to be a useful tool for inspiring themselves during the ideation. The greatest problem faced by the designers when using the AGCI interface was unclear function icons, including the icons for file lists and the delete function. Other problems concerned distinguishing between levels of main and secondary ideas, the use flexibility of the work screen, and unique requirements by individual participants, such as a function that can replace words with images. Consequently, four solutions are proposed for subsequent modifications to the AGCI prototype: modifying confusing function icons, adding symbols to distinguish between main and secondary ideas, adding instructions and descriptions for the function icons, and adjusting the use flexibility of the work screen.

4 Conclusion and recommendations

This study explored the behaviors and characteristics of designers' keyword thinking patterns and the relevant requirements for designers' online searching and retrieval. On the basis of the research results, an AGCI was developed for use in mobile devices. Numerous designers evaluated the usability of the AGCI interface prototype and the interview results can serve as a reference for subsequent modification of the AGCI. Seven behavior codes were identified from the video recordings of the designers' ideation. According to the connections among the seven behaviors, the modes of association between words and images adopted by designers during the ideation were investigated and used as design concepts for developing the prototype. The constructed AGCI interface prototype functioned as a sample for a usability interview conducted with the

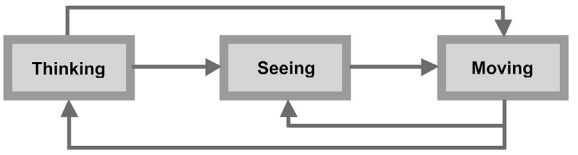


Figure 6 Idea generation mode of designers in the digital era (Revised from the design behavior framework in Cheng, 2010)

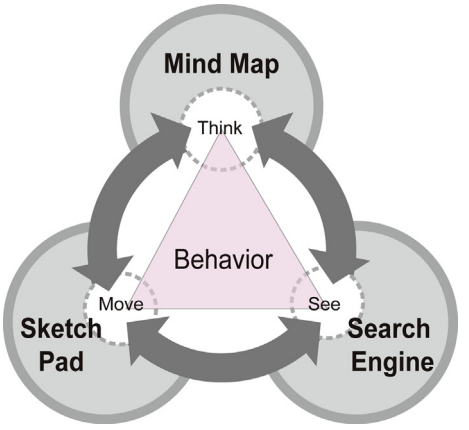
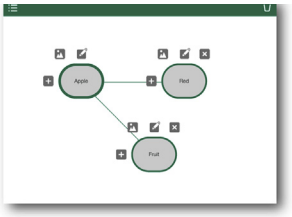
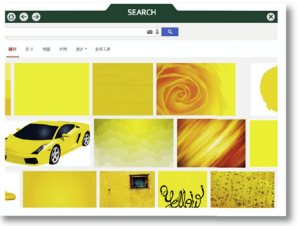
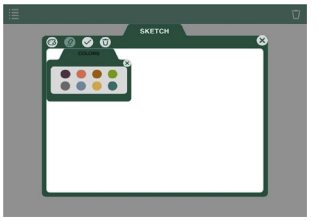


Figure 7 Corresponding relationship between AGCI functions and designers' behavior patterns during idea generation

Table 8 Design prototype of the AGCI

a. Function for idea development	*b. Function for image search*	*c. Function for sketching*
		

designers. Four major solutions for problems involved in using the prototype are proposed and can be used to modify the AGCI interface.

This study achieved the expected research outcomes in constructing a usable AGCI that can record the ideation processes of designers. In the future, this app can be employed to study designers' idea development in various design fields and may be further used to record and analyze the mode of idea development during group design.

Table 9 Examples of retrospective protocol analysis regarding operating the AGCI interface

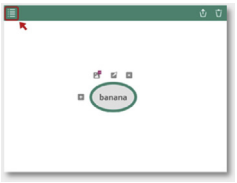
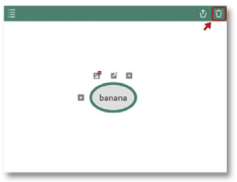
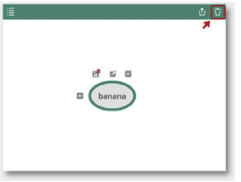
Main problems	*Retrospective protocol*	*Interface description or illustration*	*Solution*
Unclear file list on the upper left corner	K: I did not know that the file list would appear when I clicked the icon on the upper left corner. If people are familiar with this system, they will know to click here. But if they are not, they will not know. F: Yes, I clicked on this (the icon on the upper left corner) and then understood its function. Generally, we expect this type of icons to have the function of presenting app-related information, such as where the files are saved in the app system. However, currently, this app does not provide this type of information.		Use another icon or add appropriate instructions
Unclear distinction between deleting a specific object and deleting all objects by using the trash can icon	D: Because the entire page was simple, I did not know that this function was for deleting the entire creative thinking file or a specific object. The function was unclear. K: Regarding the delete function, I did not know how to delete the main ideas, and I did not know whether deleting the main ideas would delete the secondary ideas as well. Although this is logical, people generally would not understand this logic. I did not know that this function was for deleting the entire main idea. What if I want to delete the main idea but retain the secondary ideas when designing? L: I did not know how to		Add a symbol for the function of deleting main ideas and retaining secondary ideas

Table 9 (*continued*)

Main problems	*Retrospective protocol*	*Interface description or illustration*	*Solution*
	delete a new creative thinking file … I think the screen is simple and brief. I did not know whether the trash can is used to delete the entire creative thinking file or the objects in the file.		
Unclear symbol for deleting main ideas	F: Moreover, I did not know how to delete a main idea. For example, if I clicked on a main idea, I could intuitively guess that this (the trash can icon on the upper right corner) was for the delete function. The app should include a delete button, so I can directly delete an idea. I originally thought this was to clean the entire space.		Add appropriate descriptions

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