How Do Interruptions During Designing Affect Design Cognition?

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Abstract This paper reports an experimental study exploring how interruptions during designing affect designers' cognition. The results are from studying 14 teams of two undergraduate computer science students. In an experiment with three conditions, each team completed three software design tasks of comparable complexity and scope. The first condition captured designers' activities without interruptions, which served as a baseline for comparison with the other two conditions that explicitly incorporated two interruptive tasks. Design activities of all three conditions were videoed and analyzed utilizing an ontologically-based protocol analysis coding scheme. Inter-experiment comparisons showed that the design cognition of interrupted sessions were significantly different from the uninterrupted sessions, with increased cognitive efforts expended on generative aspect of designing, and decreased efforts on analytic and evaluative aspects. These differences could be accounted for by a strategic compensation, i.e., designers shifted their problem-solving strategies to make up for the interferences produced by interruptions.

Introduction

Interruptions, i.e., postponements or cessations of an ongoing task by another interpolated task, are pervasive phenomena. Most people have the experience of being interrupted by a phone call, text message or an unexpected visitor while

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engaging in a problem-solving task. Interruptions are usually considered as disruptive interferences, resulting in lowered efficiency, and/or increased error rates [1], and negative effects on affective states of people, e.g., increased anxiety [2]. Several theoretical accounts for this disruptiveness have been provided [3, 4]. The majority of the research into interruptions is concerned with simple problem-solving tasks or tasks not considered as creative in nature, and the purpose of those studies focused on general human cognitive and perceptual mechanisms.

Creative workers, such as artists and designers, often hold another interpretation for interruptions from a more macroscopic and pragmatic view. Temporarily stepping away from a wicked problem is seen as a heuristic for creative problem solving. Archimedes' "eureka" story is one of many well-known anecdotes for incubation and insights. Empirical studies also reported some improved performance after interruptions [5–7]. These findings indicate that interruptions could possibly facilitate positive incubation effects [8]. This possibility is of particular interest to designers and other creative workers.

Designers often interleave multiple design projects and non-design tasks. Interruptions are natural ingredients of authentic design activities in the real world. The effect of interruptions on design cognition however has not been adequately studied in current research on creative design. Previous work on design cognition has primarily focused on observing continuous designing processes, in which experimental settings explicitly prevented the occurrence of interruptions, e.g., [9, 10]. Recent literature showed a trend of shifting from laboratory-based design experiments to design meetings in real settings, e.g., [11, 12]. Though interruptions during the designing process were observed and audio-visually captured in these studies, they were often treated as noise and not analyzed and discussed in detail. Whether interruptions affect designers' cognition during a designing process remains unclear.

Interruptions, the act of putting the problem aside and temporarily engaging in other interpolated activities, is the hallmark of the incubation stage. Zijlstra et al. [7] argued that the implication of interruptions goes beyond the execution of additional tasks; people may adapt their problem-solving strategies to compensate for the potential performance deterioration. The beneficial effects may be due to the overcompensation. The essence of famous "eureka" story is that Archimedes reshaped his strategy to measure the volume of a crown. Similar strategy adaptions have also been observed in empirical studies involving complex tasks e.g., aviation [15].

Hypotheses

This protocol study examined the potential influence of interruptions on design cognition. Two hypotheses are tested empirically. The first hypothesis is that, regardless of the direction of any effects, interruptions affect design cognition. In other words, designers' cognitive behaviors would be significantly different between interrupted and uninterrupted conditions. This hypothesis is tested through a statistical significance comparison of the measured cognitive behaviors of design session with and without interruptions.

The second hypothesis is that interruptions during designing change designers' strategies. This hypothesis is tested by examining the change in proportions of cognitive effort on reasoning about problem analysis and solution generation. The outcome of designing is the creation of artifacts, tangible or intangible. If designers try to compensate for interruptions, the cognitive effort spent on the generative aspect of designing would be expected to be larger than in uninterrupted conditions. Consequently, the cognitive effort spent on reasoning about problem analysis and solution evaluation would decrease.

Methods

Research Participants

In the research reported in this paper, the effect of interruptions on design cognition were be explored in the domain of software design. Twenty-eight undergraduate students, currently enrolled in introductory level programming and/or software engineering classes at George Mason University, voluntarily participated in this study. They were paired into 14 design teams of two persons. All participants had at least two semesters of programming experience.

Experiment Design and Tasks

This study adopted a repeated-measures design. Each team was asked to carry out the same three types software design tasks, designing a simple algorithm, to potentially be turned into Python code. Descriptions of these tasks are summarized in Table 1. They were set in the same level of complexity, assessed by the educators and researchers. To avoid a situation where designing a solution to an initial

Table 1 Three conditions and tasks in this interruption study

Condition	Task description	Interruption task
1 (control)	To differentiate among colors, favorite numbers and hourly salaries from a list of general website inputs, to form 3 sub-lists and sort each sub-list in a natural order	Not interrupted
2 (experiment)	To find the minimum, maximum, mean, median and most frequently occurring element of a list of integers (without using built-in functions)	Two interruptions at 5 min and 20 min respectively
3 (experiment)	To find all duplicate elements and unique (non-duplicate) elements be-tween two input lists	Two interruptions in 7 min and 19 min respectively

problem would yield inspiration for the solution of a later one, the problems were written to solve unrelated tasks.

To ensure that tasks were of approximately at the same level of difficulty, each task involved the following components: (1) The sorting of a list where each element must be examined at least once; (2) an additional examination of the list where elements must be further sorted or analyzed; (3) both the sorting and analysis components involve a comparison between two elements at a time; and (4) each task involved a higher-level comparison where a single element is being compared to something more complex than just another individual element.

The design tasks are harder than a typical coding question on a final exam of an introductory programming course, but not expected to take a software professional in industry more than 15 min to design and implement. Each of the experiments allocated 45 min to the design task, in which the time spent on tasks during the interruptions was not included. Since many of the components of the solutions could be trivially solved through the use of functions in the Python standard library, subjects were asked to not use any of these built-in functions in their algorithms.

The experiment had three conditions. Each condition implemented one of three software design tasks. The first condition was conducted as the control condition, explicitly excluding any interruptions during the designing process. It served as a baseline for comparison with the other two experiment conditions. The uninterrupted condition also makes possible comparisons with other design cognition studies reported in the literature.

The other tasks comprised the experiment condition. Two interruptions were introduced in the course of designing. This study did not randomize the sequence of control and experimental conditions. Rather, the possible ordering effects or learning effects were assessed by the replication of the experiment conditions.

All interpolated tasks in the experiment conditions were structured in the same format. This format included ten sub-tasks requiring low to medium cognitive demands, including memory tasks, mental arithmetic and visual reasoning. Table 2 presents some examples for each type of question. The interrupted time points were

Table 2 Sample items for the interrupted task

Type of questions	Memory task	Mental arithmetic	Visual reasoning task
Cognitive demand	Low	Low to medium	Medium
Examples	Today's date: ________	9 times 9 = _______	How many squares do you see in the figure below?
	Your name: ________	12 times 11 = _______	

slightly different between experimental conditions, as exactly the same setting may make participants expect interruptions during the third task.

Measurements

All the design activities, including designers' utterances, drawings and gestures, were videoed and then examined using the FBS ontologically-based protocol analysis methodology [16]. In this methodology, design cognition is operationalized by a set of design issues and syntactic design processes.

A principled coding scheme, based on the FBS ontology [13, 14], that classifies designers' cognitive issues in terms of the ontological variables of function, behavior and structure, plus an external requirement and a design description, Fig. 1. The function (F) of a designed object is defined as its teleology; the behavior (B) of that object is either derived (Bs) or expected (Be) from the structure, where structure (S) represents the components of an object and their compositional relationships. These ontological classes are augmented by requirements (R) that come from outside the designer and description (D) that is the document of any aspect of designing, without introducing any new ontological classes.

Transcripts of audio-visually recorded design activities were segmented and coded using these six FBS codes. Each segment of design activity was strictly assigned with only one of the six codes, corresponding to a single underlying design issue. The design cognition of each design session was thus transformed into a sequence of design issues. A syntactic model was then applied to derive syntactic design processes as transitional processes between pairs of design issues [17]. The relationship between design issues and syntactic processes is illustrated in Fig. 1.

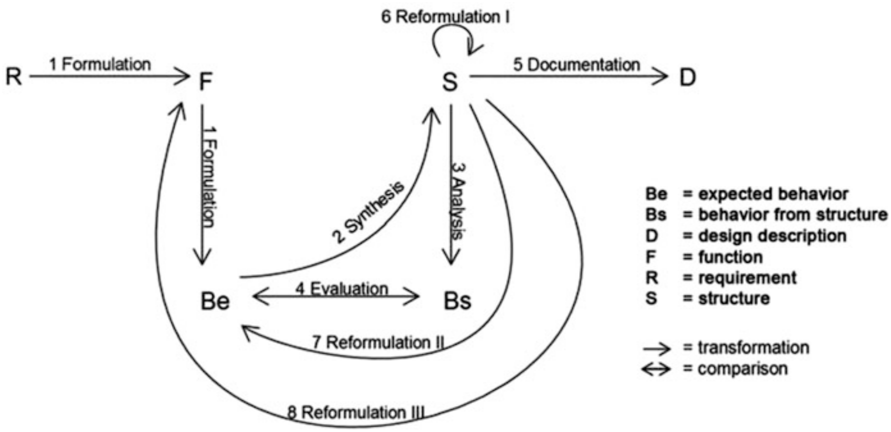

Fig. 1 The FBS ontology (After [14])

Table 3 Mapping design issues and syntactic processes onto three-pronged design model

General aspects of design cognition	Design issues	Syntactic design process
Analytic aspect (problem framing)	Requirement (R)	Formulation
	Function (F)	Reformulation II
	Expected behavior (Be)	Reformulation III
Generative aspect (solution synthesis)	Structure (S)	(Solution) synthesis
		Reformulation I
Evaluative aspect (solution evaluation)	Behavior from structure	(Solution) analysis
		(Solution) evaluation

In the design literature, the three-pronged "analysis-synthesis-evaluation" model [18–20] is a well-accepted, basic theoretical framework of designing. A mapping scheme, Table 3, was utilized to translate our research questions into operational hypotheses directly testable with the measurements of design issues and syntactic processes. As description issue and documentation process do not have equivalent components in this three-pronged design model, results concerned with these two measurements will not be elaborated or discussed further in this study.

Operational Hypotheses

Utilizing the measurements of design issues, the theoretical hypotheses presented earlier can be translated in operational terms as follows:

Hypothesis 1a (generative aspect of design cognition):
Interrupted sessions have a higher percentage of structure issues than uninterrupted sessions.

Hypothesis 1b (generative aspect of design cognition):
Interrupted sessions have a higher percentage of synthesis and reformulation I processes than uninterrupted sessions.

Hypothesis 2a (analytic aspect of design cognition):
Interrupted sessions have lower percentages of requirement, function and expected behavior issues than uninterrupted sessions.

Hypothesis 2b (analytic aspect of design cognition):
Interrupted sessions have lower percentages of formulation, reformulation II and reformulation III processes than uninterrupted sessions.

Hypothesis 3a (evaluative aspect of design cognition):
Interrupted sessions have a lower percentage of behavior from structure issue than uninterrupted sessions.

Hypothesis 3b (evaluative aspect of design cognition):
Interrupted sessions have lower percentages of analysis and evaluation processes than uninterrupted sessions.

This paper focuses on the strategic adaption due to interruptions, i.e., compensating acts for interruptions. Hypotheses 1a and 1b are our main hypotheses. Hypotheses 2a, 2b, 3a and 3b are additional hypotheses, which are natural consequences if main hypotheses are supported.

Methods of Analysis

The data analysis consists of two steps. It first examines whether there is statistically significant difference of design issue/process distributions between two experimental conditions. If no difference is found, these two experimental conditions are then collapsed by averaging the corresponding measurements, and then compared with the uninterrupted condition. Paired-samples t test or Wilcoxon signed ranks test were used, depending on whether sampling distributions of measurements were approximately normal.

If there a statistically significant difference is found between the two interrupted sessions, three conditions will be compared using one-way analysis of variance (ANOVA). All significance tests were performed using IBM SPSS v21. The effect sizes were calculated by G*Power 3.1.7.

Results

Descriptive Statistics

Applying the FBS ontologically-based segmentation and coding scheme, the intercoder agreements for each session were between 86 % and 92 %. The final data for analysis were the arbitrated data that resolved the segmentation and/or coding disagreements. After the protocol segmentation, coding and arbitration, the observations of these three conditions were transformed into an average of 210 ~ 280 (SD: 53 ~ 76) design issues and 110 ~ 148 (SD: 33 ~ 56) syntactic design processes, Fig. 2.

Figure 3 presents the distributions of design issues measured across the three conditions of this experiment. It shows that the majority of cognitive effort was expended on reasoning about structure and behaviors of design. Less than 5 % of design issues articulated requirements and functions. Two interrupted sessions, Tasks 2 and 3, share a similar design issue distribution, which were different from the distribution of the uninterrupted session, Task 1. Figure 3 shows that Task 1 has a lower percentage of structure issues, while having higher percentages of the two behavior issues.

Figure 4 illustrates the syntactic process distributions of the three experiments. The processes of formulation and reformulation III occupied a very limited

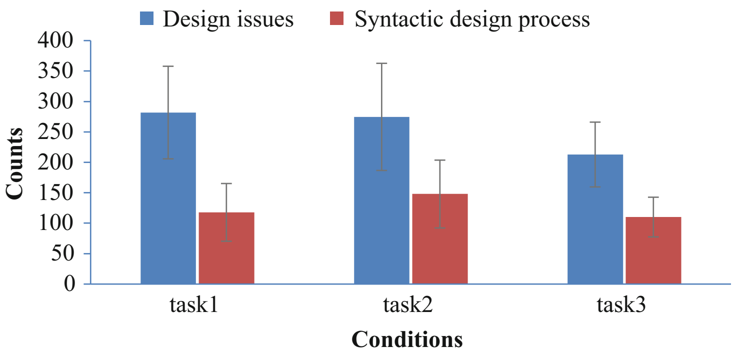

Fig. 2 Descriptive results of protocol segmentation

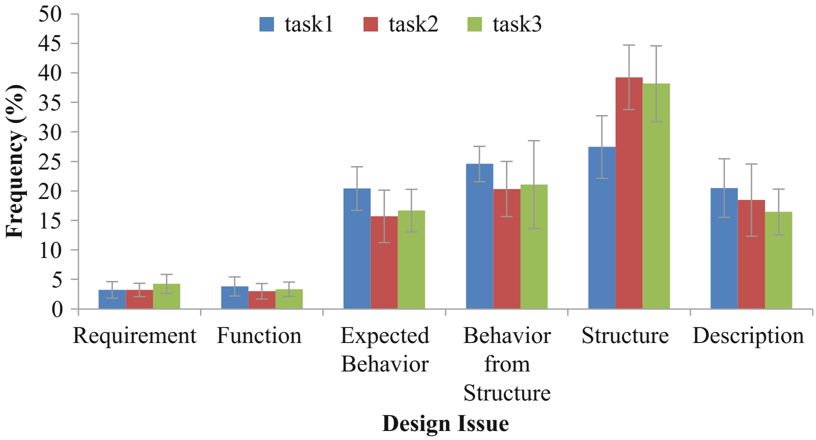

Fig. 3 Distribution of design issues (Error bars represent standard deviations)

percentage of total syntactic processes (less than 5 %). The most obvious inter-task differences can be seen in evaluation and reformulation I processes. The percentage of reformulation I processes in the uninterrupted task (task 1) was almost half of the interrupted tasks (tasks 2 and 3), but the percentage of evaluation processes was more than double of the interrupted tasks. The percentages of synthesis, analysis and reformulation II processes also tended to be different between uninterrupted and interrupted tasks.

Comparisons Between Two Experimental Conditions

Before the inferential statistical analysis, measurements of design issues and syntactic design processes were tested to determine if they fulfilled the normality

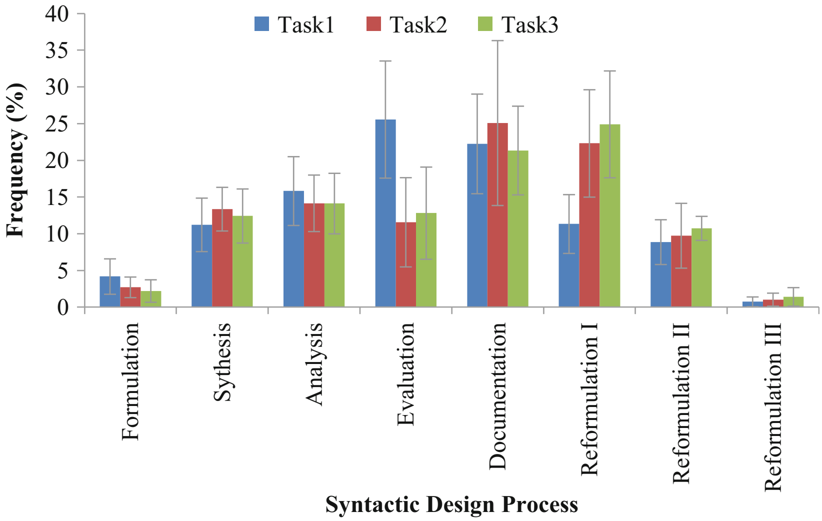

Fig. 4 Distribution of syntactic design processes (Error bars represent standard deviations)

Table 4 Pairwise comparisons of design issues between experimental conditions

Design issue	*t* statistic	Sig (2-tailed)
Requirement (R)	−1.844	0.088
Function (F)	−0.675	0.511
Expected behavior (Be)	−0.633	0.537
Behavior from structure (Bs)	−0.337	0.742
Structure (S)	0.611	0.552
Description (D)	1.217	0.245

assumption, using the Shapiro-Wilk *W* test. The paired-samples *t* test was used when the sampling distributions of two counterparts were both approximately normal. If the normality assumption was violated, the Wilcoxon signed ranks test was used instead. Statistically significant differences were assumed at a significance level (α) of 0.05.

Table 4 tabulates pairwise comparisons of design issues between the experimental conditions, Tasks 2 and 3. No statistically significant issue differences were observed between these two interrupted sessions. The same negative results were replicated using the measurement of syntactic design processes, Table 5. The homogeneity of the two interrupted conditions was supported. Measurements of these two experiment conditions were thus aggregated, and compared with the uninterrupted (control) condition as a whole.

Table 5 Comparisons of syntactic processes between experimental conditions

Syntactic design process	*t*/*W* statistic	Sig (2-tailed)
Formulation	0.282	0.778
Synthesis	0.639	0.534
Analysis	0.024	0.981
Evaluation	−0.973[a]	0.331
Documentation	1.193	0.254
Reformulation I	−1.076	0.302
Reformulation II	−0.747	0.469
Reformulation III	−0.628[a]	0.530

[a]W statistic of paired-sample Wilcoxon Signed Rank test; the remaining statistics are the t statistic of paired-sample *t* test

Table 6 Inter-conditional comparisons of design issues

Design issue	*t* statistic	Sig (2-tailed)	*d*
Requirement (R)	−1.490	0.162	−0.413
Function (F)	1.318	0.212	0.366
Expected behavior (Be)	3.512	0.004*	0.974
Behavior from structure (Bs)	2.137	0.054	0.593
Structure (S)	−5.178	0.000*	−1.436
Description (D)	2.075	0.060	0.575

*Statistically significant at the level of $p \leq 0.05$

Comparisons Between the Interrupted and Uninterrupted Conditions

Table 6 and Fig. 5 summarize the inter-conditional comparisons using the measurements of design issues. Differences between uninterrupted and interrupted tasks were mainly found in the issues of structures and expected behaviors. Compared with the uninterrupted condition, designers exhibited a significantly higher percentage of structure issues and significantly lower percentage of expected behavior issues, when they were interrupted during designing. The magnitudes of difference, indicated by Cohen's *d*, were substantially large in terms of these two issues. The interrupted condition also had lower percentages of behavior from structure and description issue than uninterrupted condition. The differences were of marginal significance, and of medium effect size in terms of difference magnitude.

The differences across interrupted and uninterrupted conditions were then compared using the measurements of syntactic design processes, Table 7 and Fig. 6. The inter-conditional differences were mainly observed in evaluation and reformulation I processes. When interrupted, designers exhibited a significantly higher percentage of evaluation process, and a significantly lower percentage of reformulation I process. The effect sizes of difference were large in terms of Cohen's *d*. There was another marginal difference observed in formulation process ($p = 0.06$). But the frequency of this process was very low (about 5 % of total syntactic processes),

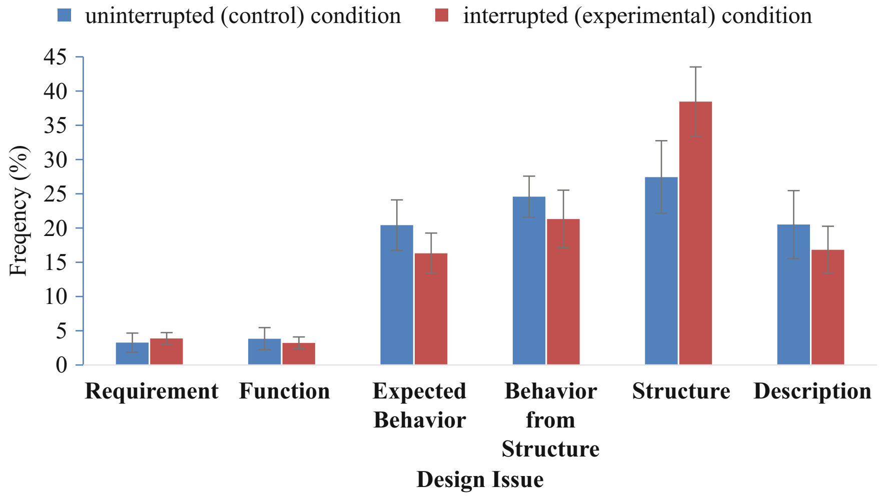

Fig. 5 Distribution of design issues (Error bars represent standard deviations)

Table 7 Inter-conditional comparisons of syntactic design process

Syntactic design process	*t*/*W* statistic	Sig (2-tailed)	*d*
Formulation	2.076	0.060	0.576
Synthesis	−1.321	0.211	−0.366
Analysis	0.859	0.407	0.238
Evaluation	4.971	0.000*	1.379
Documentation	−0.175[a]	0.861	−0.005
Reformulation I	−5.515	0.000*	−1.529
Reformulation II	−1.572[a]	0.116	−0.379
Reformulation III	−1.684	0.118	−0.467

[a]W statistic of paired-sample Wilcoxon signed rank test; the rest statistics are t statistic of paired-sample *t* test
*Statistically significant at the level of $p \leq 0.05$

we thus did not consider that the difference in this process was able to contribute a substantial difference in terms of overall design cognition.

Discussions

The experiments reported in this paper provide an opportunity to examine the effects of being interrupted during a designing process. Design cognition measured in the two interrupted conditions showed a statistical homogeneity: all pairs of design issue and syntactic design process were not significantly different between Tasks 2 and 3. Results from the comparisons between interrupted and uninterrupted

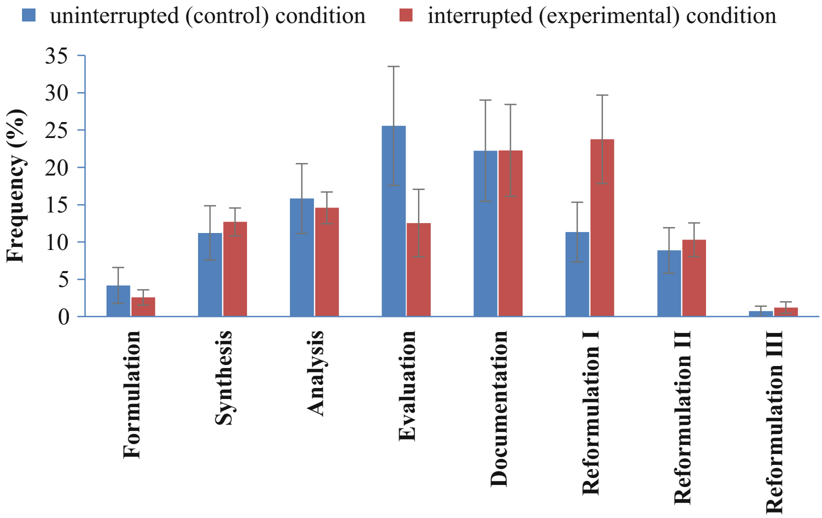

Fig. 6 Distribution of design issues (Error bars represent standard deviations)

conditions generally supported our hypotheses that the interruptions influence designers' cognition.

Main Hypothesis: Interruptions Make Designers More Focus on Solution Synthesis

This study used the structure issue and the syntactic processes of synthesis and reformulation I to operationalize the generative aspect of design cognition. Except from synthesis process (no statistically significant difference were found), results of the other two measurements strongly supported our main hypothesis. The percentages of structure issues and reformulation I processes in the interrupted condition were both significantly larger than the uninterrupted control condition, and the effect sizes of pairwise differences were all substantially large in terms of Cohen's d (-1.44 for comparisons of structure issue, and -1.53 for reformulation I process).

Interruptions could be detrimental to the performance of the primary task, as additional cognitive efforts are expended towards the interpolated task. The increasing percentages of generative aspect of cognition measurements during interrupted sessions suggest that designers may make some strategic shifts to increase problem-solving efficiency and compensate for the possible negative influences of interruption.

This solution-orienting effect of interruptions may have implications in creativity theory. Temporary shifts away from an ongoing task are often discussed as a stage for "incubation". The beneficial strategic adaption, more concentrated on solution generation, may partially explain the incubation effects [21–23].

Additional Hypotheses: Interruptions Make Designers Less Focused on Problem Analysis and Solution Evaluation

As a consequence of increased focus on solution generation, designers' cognitive effort spent on other aspects of designing, i.e., problem analysis/formulation and solution evaluation, are reduced during interrupted sessions.

The evidence of reduced focus on problem analysis/formulation was obtained from the expected behavior issues, Table 6. A large effect size (Cohen's $d = 0.97$) was observed.

The lowered focus on solution evaluation was mainly demonstrated in the syntactic processes of evaluation. Figure 6 shows that this syntactic process measured in the interrupted condition was only half of its uninterrupted counterpart. The dramatic drop of evaluation effort suggests that designers' compensating strategies come with a cost: designers may not critically scrutinize the consequences of their design solutions as much when they are interrupted amidst designing compared to not being interrupted.

The results about behavior from structure issues also complied with the pattern that designers in interrupted conditions expended less effort on the evaluative aspect of designing. The interrupted condition had a lower percentage of behavior from structure issue than the uninterrupted condition (21.3 % vs 24.6 %, Fig. 5) at the marginal significance level.

Issues Related to Validity

In this paper, we sought to expand upon traditional design tasks that have been previously studied by examining a more complex algorithm construction session in a group setting. Although we believe that the results of this study likely generalize to a larger population, our experiments are a first step in this domain, and may be subject to some limitations. We used students with approximately two semesters of programming experience as participants. It is possible our conclusions do not generalize beyond this group, and that subjects with more programming experience may be less affected by interruptions. Future work will be able to explore a broader subject pool.

Conclusion

This study explored 14 student teams' software design activities in uninterrupted and interrupted conditions, using the FBS ontologically-based protocol analysis methodology. Interruptions are often seen as a hallmark of an incubation period. Understanding the role of interruptions could help us to take advantage of their beneficial incubation effects and prevent their detrimental influences. Results from this preliminary study indicate that interruptions could significantly affect designers' cognition. In particular, designers were more focused on reasoning about solution generation during the interrupted conditions. This may be explained by designers shifting their problem-solving strategies to make up for interruptions [24, 25]. Details of strategic changes, as well as the pros and cons of this strategic compensation, will be further investigated in the future studies.

The significance of studying the effects of interruptions transcends its potential role in incubation and its consequential connection to creativity. Today we live in a world where interruptions are increasing: emails, text messages, Facebook messages and tweets are displayed or notified to us as they occur. It becomes increasingly difficult not to be interrupted while we are carrying out our tasks. The empirical results from these experiments show that interruptions have an effect on the designers while they are designing.

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References

1. McFarlane DC (2002) Comparison of four primary methods for coordinating the interruption of people in human-computer interaction. Hum Comput Interact 17:63–139. doi:10.1207/S15327051hci1701_2
2. Bailey BP, Konstan JA (2006) On the need for attention-aware systems: measuring effects of interruption on task performance, error rate, and affective state. Comput Hum Behav 22:685–708. doi:10.1016/j.chb.2005.12.009
3. Altmann EM, Trafton JG (2002) Memory for goals: an activation-based model. Cognit Sci 26:39–83. doi:10.1016/S0364-0213(01)00058-1
4. Trafton JG, Monk CA (2008) Task interruptions. In: Boehm-Davis DA (ed) Reviews of human factors and ergonomics, vol 3. Human Factors and Ergonomics Society, Santa Monica, pp 111–126
5. Speier C, Vessey I, Valacich JS (2003) The effects of interruptions, task complexity, and information presentation on computer-supported decision-making performance. Decis Sci 34:771–797
6. Ratwani RM, Trafton JG, Myers C (2006, 16–20 Oct) Helpful or harmful? Examining the effects of interruptions on task performance. In: Proceedings of the Human Factors and Ergonomics Society, 50th Annual Meeting, San Francisco, CA. Sage Publications, pp 372–375

7. Zijlstra FRH, Roe RA, Leonora AB, Krediet I (1999) Temporal factors in mental work: effects of interrupted activities. J Occup Organ Psychol 72:163–185
8. Sio UN, Ormerod TC (2009) Does incubation enhance problem solving? A meta-analytic review. Psychol Bull 135:94–120. doi:10.1037/a0014212
9. Cross N, Christiaans H, Dorst K (eds) (1996) Analysing design activity. Wiley, Chichester
10. Gero JS, Jiang H, Williams CB (2013) Design cognition differences when using unstructured, partially structured, and structured concept generation creativity techniques. Int J Des Creat Innov 1:196–214. doi:10.1080/21650349.2013.801760
11. McDonnell J, Lloyd P (eds) (2009) About: designing: analysing design meetings. CRC Press, Boca Raton
12. Gero JS, Jiang H, da Silva VS (2013) Exploring a multi-meeting engineering design project. In: Chakrabarti A, Prakash RV (eds) ICoRD' 13: global product development lecture notes in mechanical engineering. Springer, New Delhi, pp 73–84. doi:10.1007/978-81-322-1050-4_6
13. Gero JS (1990) Design prototypes: a knowledge representation schema for design. AI Mag 11:26–36
14. Gero JS, Kannengiesser U (2004) The situated function-behaviour-structure framework. Des Stud 25:373–391. doi:10.1016/ j.destud. 2003.10.010
15. Latorella KA (1999) Investigating interruptions: implications for flightdeck performance. Virginia National Aeronautics and Space Administration, Hampton
16. Kan JWT, Gero JS (2009) Using the FBS ontology to capture semantic design information in design protocol studies. In: McDonnell J, Lloyd P (eds) About: designing: analysing design meetings, CRC Press, Boca Raton, pp 213–229
17. Gero JS (2010) Generalizing design cognition research. In: Dorst K, Stewart SC, Staudinger I, Paton B, Dong A (eds) DTRS 8: interpreting design thinking. University of Technology Sydney, New South Wales, pp 187–198
18. Archer LB (1984) Systematic method for designers. In: Cross N (ed) Developments in design methodology. Wiley, New York, pp 57–82
19. Cross N (2008) Engineering design methods: strategies for product design, 4th edn. Wiley, Chichester
20. Pahl G, Beitz W, Feldhusen J, Grote K-H (2007) Engineering design: a systematic approach (trans: Wallace K, Blessing L, 3rd English edn.). Springer, New York
21. Smith SM, Dodds RA (1999) Incubation. In: Runco MA, Pritzker SR (eds) Encyclopedia of creativity, vol 2. Associated Press, San Diego, pp 39–44
22. Brockett C (1985) Neuropsychological and cognitive components of creativity and incubation, Unpublished Doctoral Dissertation, Virginia Commonwealth University
23. Dodds RA, Ward TB, Smith SM (2004) A review of the experimental literature on incubation in problem solving and creativity. In: Runco MA (ed) Creativity research handbook, vol 3. Hampton Press, Cresskill
24. Elio R, Scharf PB (1990) Modeling novice-to-expert shifts in problem-solving strategy and knowledge organization. Cognit Sci 14:579–639. doi:10.1207/s15516709cog1404_4
25. Rijkes CPM, Kelderman H (2007) Latent-response rasch models for strategy shifts in problem-solving processes. In: Carstensen CH (ed) Multivariate and mixture distribution rasch models. Springer, New York, pp 311–328