

Modeling Cognitive Strategies during Complex Task Performing Process

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Abstract

The purpose of this study is to examine individuals' computer based complex task performing processes and strategies in order to determine the reasons of failure by cognitive task analysis method and cued retrospective think aloud with eye movement data. Study group was five senior students from Computer Education and Instructional Technologies Department at a state university. A computer based complex task including a logical reasoning process was developed and utilized. Data was collected with cued retrospective think aloud containing a gaze video replay and eye tracking. All the retrospective protocols were transcribed for analysis then a coding schema was developed iteratively from segments. By drawing area of interest fields(AOI) of task panel, eye movement data in specific processes and fields were analyzed by using fixation duration and fixation count metrics.

None of the participants completed the task successfully within the given amount of time (max-10 min.). The findings yielded seven cognitive strategies ("*information gathering-reviewing*", "*identification well-defined instructions*", "*cue-seeking*", "*using cues*", "*assumption*", "*trial and error*" and "*crosschecking*") and their actions obtained from the task performing process. Furthermore, this process is modeled by defining sequences and the relations between the actions and cognitive strategies. It has been revealed that trial and error is the most employed strategy and participants used trial and error without reasoning. Moreover, it has been revealed out that participants mostly failed in choosing and using the right strategy.

Keywords: cognitive task analysis, retrospective think aloud, eye movements, complex task

Introduction

When approaching a complex cognitive task during problem solving process, individuals are reported to determine and apply various cognitive strategies on the way of reaching a solution. Determining successful and unsuccessful strategies is crucial when making instructional decisions. Moreover, it is equally important to describe what makes task a complex task. In his well cited study, Campbell (1988), reviewed the related research on task complexity and concluded that task complexity changes across personal characteristics (experience, familiarity, interests, working memory, span of attention and substantial cognitive demand) and task characteristics (multiple ways to arrive at desired end-state, multiple desired outcomes to be attained, conflicting interdependence among paths to multiple

outcomes and the presence of uncertainty). Web based environments or online learning environments can be considered as rather complex environments since they consist of various related or independent visual, audio or textual components. When individuals participate to these environments for various purposes and tasks i.e. learning, information seeking, reading or writing, there have been different intrinsic and extrinsic factor that effect to this process.

In research related to performing complex tasks in learning environments, researchers generally focus on describing a successful process of task, modeling the process of successful individuals (i.e. experts) (Ertmer et.al., 2008a) and determining the differences between experts and novices (Ertmer et.al., 2008b; Brand-Gruwel, Wopereis & Vermetten, 2005). However it is critical to determine factors that cause failure by examining thoroughly the reasons of why individuals become unsuccessful, at which stage and how frequent failure emerges and which processes cause them to fail. These findings would help to modify learning environments with regard to elimination of problems and training of individuals with strategies related to solutions of these problems. Thus, in this study, it was aimed to examine individuals' computer based complex task performing process and strategies in order to determine the reasons of failure by the cognitive task analysis method and cued retrospective think aloud containing eye movement data. In this section, first, what makes a task complex in learning environments will be outlined. Secondly, cued retrospective think aloud methodology through eye-movement replay will be explained.

Complex Tasks in Learning Environments

Complex tasks are cognitively demanding tasks in which individuals have to organize a large number of different types of cognitive processing, often not possible to make an automated or standardized response to a situation, which requires some predicting and comparing to choose a sequence of activity since there are usually several simultaneous goals to be met (Bainbridge, 1997). Marmaras and Pavard (1999) stated that complex task could be complex both at the cognitive level and at the level of the environment and these tasks require different types of problem solving such as decision making, diagnosis and planning, and complex cognitive activities such as anticipation, monitoring and mental calculations.

Complex task environments have some common characteristics which are generally specified as (Marmaras & Pavard, 1999; Funke, 1991);

- They consisted of interrelated and interacting dynamic components and factors. Complexity of the task as defined by the number of variables can be depending on also the degree of the connectivity among the variables and the type of functional relationship.
- Semantic content of the task is rich. This richness of semantic content often reduces the uncertainty.
- Events can occur at undetermined times and the nature of the problem to be solved can change
- There is uncertainty regarding the time at which one or more events occur, and the severity of changes they cause to the work system. Not every action shows immediate consequences, effects often can occur with time delay.
- There are multiple quantitative and qualitative objectives to be achieved, often conflicting, and with no predetermined hierarchy. Precision of goal definition, whether the goal is defined, whether there are multiple goals or are they contradictory.
- There is a time limit in complex tasks which require immediate decisions.
- Making a mistake could cause the successive mistakes.

Cognitive load has been argued as main characteristics of complex task performance (Sweller & Chandler, 1994) and it has been stated that the individuals can compensate for an increase in cognitive load (e.g., increasing task complexity) by investing more mental effort to maintain their performance at a constant level (Sweller, van Merriënboer, & Paas, 1998).

Van Merriënboer, Kester and Paas (2006) suggested that in well-designed instructional environments extraneous load should be decreased and germane load should be optimized within the limits of total available capacity in order to prevent cognitive overload.

Four key components of learning environments for complex tasks are claimed as (Merriënboer, 1997; van Merriënboer, Kirschner, & Kester, 2003; van Merriënboer, Kester, & Paas, 2006);

- Learning tasks should be based on real-life tasks and fulfill the role of a backbone for the training program.
- There is supportive information available to learners to help them to perform the problem-solving and reasoning aspects of learning tasks.
- Procedural information is presented to learners to perform the routine aspects of learning tasks.
- Part-task practice are included to provide learners with additional practice for routine aspects of the complex task that need to be developed to a very high level of automaticity.

Using Cueing Retrospective Think Aloud Method in Cognitive Task Analysis through Eye-Movement Replay

Retrospective think aloud is a method which is based on gathering information by think aloud not concurrently but after the performance is over. Concurrent think aloud is stated to have some limitation especially when the task involves high cognitive load (i.e. complex tasks) since verbalizing information while performing tasks might distract subjects' attention and concentration and increase cognitive load. (Russo, Johnson and Stephens, 1989; Branch, 2000). Retrospective think aloud method is suggested to overcome these negative effects of concurrent verbal protocols (Guan, Lee, Cuddihy, & Ramey, 2006). Even so, since retrospective think aloud is also have been criticized for forgetting information and fabrication of process (van Someren, Barnard, & Sandberg, 1994; van Gog, Paas, van Merriënboer, & Witte, 2005), presenting visual cues belonging the task process stated to stimulate verbal reports of individuals (van Gog, 2006; Guan, Lee, Cuddihy, & Ramey, 2006). The general technique to stimulate retrospective think aloud is to present users a playback video of task session which facilitate the retrieval information from memory and provide veridicality which is an important issue for research related to memory processes and problem solving strategies (Hyrskykari et.al. 2008).

Since eye movement provides an objective measurement of cognitive processes (Rayner, 1998), they might additionally facilitate reporting thoughts and eliciting comments from users when they are used as cue (Russo, 1979). It is suggested that containing information about information processed and area focused during the task, eyes provide a window into mental life and eye movement have the characteristics to continuously track both in space and time the evolution of mental events (Nakatani & Pollatsek, 2004; De'Sperati, 2003). However, since solely eye movement data is limited to show the experimenter *where* the participant looked but not reveal out the answer of the *why* questions with user's intention, it is important to support eye movement data with verbal reports (Seagull and Xiago, 2001; Eger, Ball, & Dodd, 2007; Hyönä, 2010).

Both of the verbal protocols and the eye movements reveal valuable information about cognitive processes. Therefore using them together provides both subjective and objective data to the researcher and allows the researcher(s) triangulate data to enhance validity of the findings. Already there have been usability and cognitive task analysis studies that applied these two methods together (Guan, Lee, Cuddihy and Ramey, 2006; Tobii 2009; (Jarodzka, Scheiter, Gerjets, & Van Gog, 2010; De Koning et al., 2010). Since cognitive task analysis is a process to determine cognitive activities required accomplishing a given task and yield information about the knowledge, thought processes, and goal structures (Chipman, Schraagen, & Shalin, 2000), choosing appropriate knowledge elicitation techniques to obtain the underlying cognitive processes and structures is important (Seagull & Xiago, 2001).

Cooke (1999) suggested three main categories of cognitive task analysis techniques as; (a) observation and interviews, (b) process tracing, and (c) conceptual techniques. In process tracing techniques, to increase the information yield for practical applications, protocols may be supplemented with retrospective review of videotapes with probe questions and eye movement data to provide an effective memory cue facilitating recall (Chipmann, Schraagen, & Shalin, 2000; Seagull & Xiago, 2001). Guan, Lee, Cuddihy and Ramey, (2006) compared subjects' verbalizations with their eye movements and found that stimulated with gaze data RTA is valid and reliable method that provides a valid account of what people attended to in completing tasks, has a low risk of introducing fabrications, and its validity is unaffected by task complexity.

Consequently, supporting and validating users' subjective verbal data which has limitations and deficiencies, with objective eye movement data can be regarded essential to provide rich and valid data (Hyönä, 2010). From this point of view, this study aimed to investigate cognitive processes of individuals during a complex task performing process, executing a cognitive task analysis with stimulated retrospective think aloud containing a gaze video replay and eye tracking techniques to overcome user's loss of concentration and distracting cognitive resources problems.

Method

This study employed the cognitive task analysis to examine individuals' complex task performing process in a computer based task. Data is collected with cued retrospective think aloud containing a gaze video replay and eye tracking techniques.

Participants

In this study, purposive sampling procedure was applied as a qualitative sampling method. In purposive sampling, subjects are selected because of some their characteristics to define a distinctive subgroup from a small sample. This selection method which focuses on a particular unit or subgroup that is considered homogeneous, doesn't aim to generalization but providing information rich cases for in depth study (Patton, 1990; Marshall, 1996).

Since only a single difficulty level complex task was used in this study, study group was selected from same department and the same degree class to fix complexity and difficulty of the task with respect to age, class, department, prior courses variables etc.. The complex task was consisted of problem which is similar to "Academic Personnel and Graduate Education Entrance Examination" questions. Due to the purpose of this study was to examine reasons of failure, especially novice participants, in other words students who have not experienced this exam and also have not started to study for this exam

yet, are considered. From this point senior students who have not entered but also proximate to enter this exam completing their undergraduate education and will practice their theoretic information in real life problems were chosen for this study.

Accordingly, eight seniors from Computer Education and Instructional Technologies Department were selected randomly and interviewed to inform about the study. They were also asked if they started to study for "Academic Personnel and Graduate Education Entrance Examination" by solving any pilot exam tests. Six of the seniors were accepted to be volunteers to participate in this study and declaring that they have not started to prepare to the exam yet. One of the participants was excluded from study because of the problematic data. Consequently, study group is consisted of five senior students from Computer Education and Instructional Technologies Department who were considered as novices.

Instruments and Materials

Complex Task: A computer based complex task which is based on logical reasoning was used. The task consisted of a set of cues, an empty 5X5 matrix field and information items. A screen view of task is presented in figure 1:

VERİLEN BİLGİLER:

1. İngiliz kırmızı evde yaşıyor.
2. İsveçli köpek besliyor.
3. Danimarkalı çay içiyor.
4. Yeşil evin sahibi kahve içiyor.
5. Beyaz evin solunda yeşil ev var.
6. Kuş besleyen kişi Porsche marka araba kullanıyor.
7. San evin sahibi Ferrari marka araba kullanıyor.
8. Tam merkezdeki evde yaşayan kişi süt içiyor.
9. Norveçli ilk evde oturuyor.
10. Kedi besleyen kişinin evinin yanındaki evde oturan kişi BMW marka araba kullanıyor.
11. Ferrari marka araba kullanan kişinin evinin yanındaki evde oturan kişi at besliyor.
12. Audi marka araba kullanan kişi aynı zamanda soda içiyor.
13. Alman, Alfa Romeo marka araba kullanıyor.
14. Mavi evin yanında oturan kişi Norveçli.
15. Su için kişinin komşusu BMW marka araba kullanıyor.

KURALLAR:

- 1- 5 farklı renkte 5 ev var.
- 2- Bu evde yaşayan kişiler;
 - farklı türde içecek içiyor,
 - farklı marka araba kullanıyor,
 - farklı cins hayvan besliyor.
- 3- Araba, içecek ve hayvanların hiçbirini aynı değil.

Information items field:

Alfa Romeo	Alman	At
Audi	Balık	Beyaz
BMW	Çay	Danimarkalı
Ferrari	İngiliz	İsveçli
Kahve	Kedi	Kırmızı
Köpek	Kuş	Mavi
Norveçli	Porsche	San
Soda	Su	Süt
Yeşil		

Figure 1. Screenshot of the Computer Based Complex Task

Problem solution field is comprised of 5X5 matrix. Using the cues and deducing the logical conclusions individuals are required the match five different nationalities with five different color houses, five different animals, five different car models and five different beverages. None of the car models, animals, beverages or house colors must not to match more than once. Participants are required to place the information items (right side) to the matrix field (on left side) by utilizing from the given 15 cues (upper part). While some of the cues were well defined, having explicit certain statements, some of them were ill structured not containing precise information to go on but only usable after utilizing from well defined cues to make inference by making their relations with other cues. Participants had the flexibility to re-change information items' places or undo the actions. Totally 10 minutes were given everybody to solve the complex task. A pilot study was conducted with 3 graduate students, as experts. Since two of experts could solved the problem in given time, time is set to with ten minutes.

Eye tracking: Tobii T120 eye tracker was used to record video of complex task performing process and eye movements. Eye tracker was integrated within the panels of the monitor and the tracking system had a 120 Hz sampling rate and an accuracy of 0.5°. Participants were seated 60-65 cm distance from eye tracking monitor and calibration was executed for each participants. Tobii Studio's RTA feature was used to playback to participants their task process video and to record audio of retrospective think aloud verbal reports.

Data Collection Process

Data were collected in individually sessions independently from others for each participant. A total experiment session was lasted in an average 40 minutes for each participant.

Task implementation process consisted of three stages; 1) prior practicing and training individuals about original task (approx., 12min); 2) performing task (10min.) and 3) retrospective think aloud (approx. 15-20min).

Pre-training and practice session: Individuals solved a pre-experiment task which is a simpler reasoning problem similar to the original task, to practice and become familiar with the solving principles of the experimental task. This practice problem is consisted of matching items and information cues as in original task but on a 4X3 matrix field. This task was executed paper-pencil based. Correctness or falseness was not taken into account in the analysis or anywhere of the study.

After the pre-experimental task a demo tutorial video was watched to the participants that contained instructions about to solution of experimental task. This training tutorial video was prepared by using Captivate program and consisted of audio visual instructions and small examples about problem. This video took approximately 2.5 - 3 minutes and if the participants needed they are allowed to watch more than one times.

Experimental complex task: After the pre-training session participants were seated to computer which has an integrated eye tracker and the task was opened on the computer. After the participants were calibrated they were cautioned to sit inactively so far as possible and informed about the task will be finished end of the 10 minutes.

After the 10 minutes, researcher notified the participants time is up and terminated the program.

Retrospective think aloud session: After the task performance participants had a five minutes break. Then participants were instructed about directives of think aloud procedure. Researcher told that a recording of eye movements during their own task performing process will be shown and they are required to tell through what were you doing and thinking at the time. Participants were informed that red dots represent where they were looking and these dots become larger when/where they look longer.

The playback control and the play speed control were given to the participants, so they had the flexibility of re-watching, stopping or forwarding. If the participants fell silent a long time, researcher intervened to think aloud.

After the retrospective think aloud session participant were informed the experimental session has finished and were thanked for their participation.

Data Analysis

Data analysis process was conducted according to stages of Cresswell's (2007) data analysis spiral. At first all the retrospective verbal reports were transcribed into separate text files for each participant. Then all the transcription files were imported into QSR-Xsight qualitative data analysis program. Text data was disaggregated into segments by analyzing content data for similar patterns and grouping conceptually similar contents. After that a code scheme was developed by an iterative process by comparing all segments with others and with video records until a sufficient coding scheme developed çalışılmıştır (Glaser & Strauss, 1995).

Coding scheme was developed to reveal out individual's task performing strategies and actions that are employed with those strategies. Although individuals' verbal reports constituted the primary source to inference strategies and actions, but also researchers checked those verbal reports from video recording for verifying inferential and making up missing statements. At first, 20 strategies and 31 actions that are put into with those strategies were eliminated. After that, by continuing recursive analysis, some of the similar or overlap categories were gathered under same category and also some categories were excluded since found to be not reflecting the original action in the video record. As a result, after the iterative coding process seven strategies and nine actions that are employed with one of those strategies were determined. A flowchart of the algorithm of complex task process was developed that shows sequence of the actions and relations of with each other and complex task performance process was modeled with frequency of the strategies and the actions.

Triangulation, member checking and peer review were employed for credibility and trustworthiness of the study (Lincoln & Guba, 1985). Triangulation of the method by conducting research with both of the qualitative and quantitative data provides a broader, deeper perspective, minimize the bias and enhance the validity, reveal the various dimensions of given phenomena (Perone & Tucker, 2003). Especially using the objective and subjective data together and supporting these data with each other will enhance reliability and validity of the research (Cresswell, 2007). In this study, data was collected by both retrospective think aloud and eye tracking for cognitive task analysis. Subjective verbal reports from retrospective think aloud was supported by objective eye movement data from eye tracking.

Member checking is also another most crucial technique for establishing credibility which is based on verifying or testing the data, categories, coding scheme, interpretations or conclusion with participants

(Lincoln & Guba, 1985). Within the scope of this study, the process model of the task performance that includes strategies and actions of participants were presented and described one of the participants and asked whether this process model reflects his own task performance process. He confirmed that this model reflects his general task solution process.

For the inter rater reliability peer debriefing was used to legitimize the interpretations and intercoder agreement coefficient was calculated. Miles and Huberman's (1984) formula ($\frac{\text{agreements}}{\text{agreements} + \text{disagreements}}$) was used to calculate intercoder agreement coefficient and found to be %94,5. The mean interrater reliability was adequate with respect to the suggestion that 70 per cent intercoder reliability is considered satisfactory (Miles and Huberman, 1984).

Findings

The findings of this study will be presented in two sections. First, task completion performance will be analyzed and narrated. Secondly, cognitive strategies and actions during complex task performance will be presented.

Task Completion Performance

The task contained 25 information items to be placed in a correct order in a given period of time. None of the participants completed this task successfully in the given period of time. The first participant (P1) matched all of the 25 information items but only 2 of them were in their correct places while others were incorrect. However, when the participant checked his answer with cues he realized he made mistake. Due to the time limitation, he did not have time to go back to correct his choices.

The second participant (P2) placed 14 of the information items on the matrix, among which 11 of them were on correct but 3 of them were on incorrect positions. The third participant (P3) placed 21 of the information items on the matrix, among which 5 of them were on correct position, yet 16 of them were on incorrect positions. The participant four (P4) placed 15 of the information items on the matrix, among which 9 of them were placed on their correct position, but 3 of them were not. Similarly, participant five (P5) could not complete the task in the given time period (ten minutes). P5 placed 12 of the 25 information items on the matrix, among which 6 of them were placed on their correct positions.

Cognitive Strategies and Actions during Complex Task Performance

The common cognitive strategies with the actions of these strategies were determined by cognitive task analysis during a complex task solution for five participants.

Cognitive strategies are defined as procedures or mental routines that support individuals as they develop internal procedures which enable them to perform higher-level operations or accomplishing cognitive goals (Rosenshine, Meister and Chapman, 1996; Dole, Nokes and Drits, 2008). As well as determining cognitive strategies and action of participants, their eye movements also recorded to verify verbal reports and to facilitate participants' think aloud. To clarify where the participants more and longer fixate on and for which strategy they use which part, four main area of interests (AOI) were driven on the problem field: "cue field", "placement matrix", "information items" and "rules". The drawn AOIs of the problem field are presented in Figure 2:

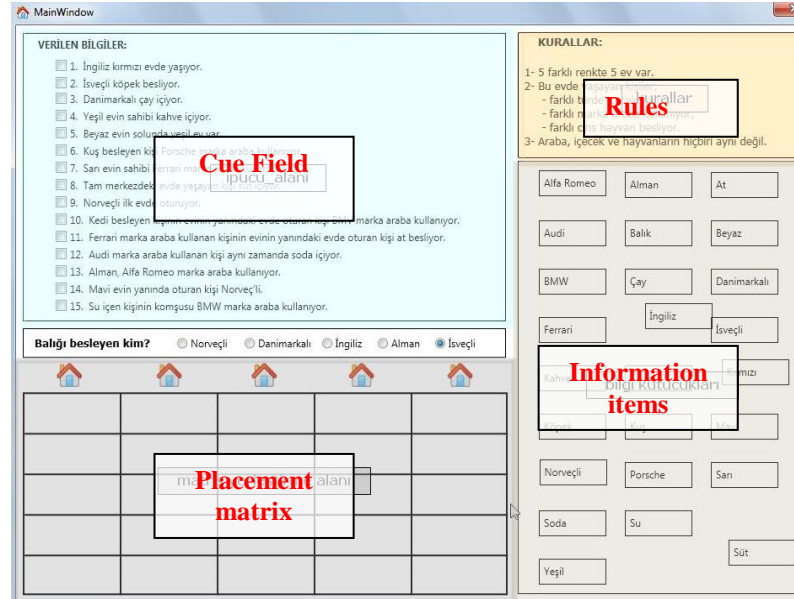


Figure 2. Area of Interests of Complex Task Field

Seven cognitive strategies ("information gathering-reviewing", "identification well-defined instructions", "cue-seeking", "using cues", "assumption", "trial and error" and "crosschecking") were obtained from the task performing process. In addition eight actions were observed related to strategies.

The frequency of these strategies and their related actions are presented in Table 1:

Table 1. Frequency of the Strategies and their Related Actions

Strategy	Action	Frequency of action	Frequency of strategy
Information gathering-reviewing	Identifying problem/task	8	8
Identification well-defined instructions	Seeking for well defined cue statements.	13	$13+7=20$
	Choosing/placing well defined cue statements.	7	
Cue-seeking	Scanning	4	$4+5=9$
	Relating	5	
Using cues	Relating	10	$10+16=26$
	Placement	16	
Assumption	Placement	9	9
Trial and error	Placement	21	21
Crosschecking	Detecting mistakes	16	$16+5=21$
	Confirmation	5	

Complex task performing process is modeled by defining sequences and relations between the actions and cognitive strategies based on verbal report and observations of video records (Figure 3).

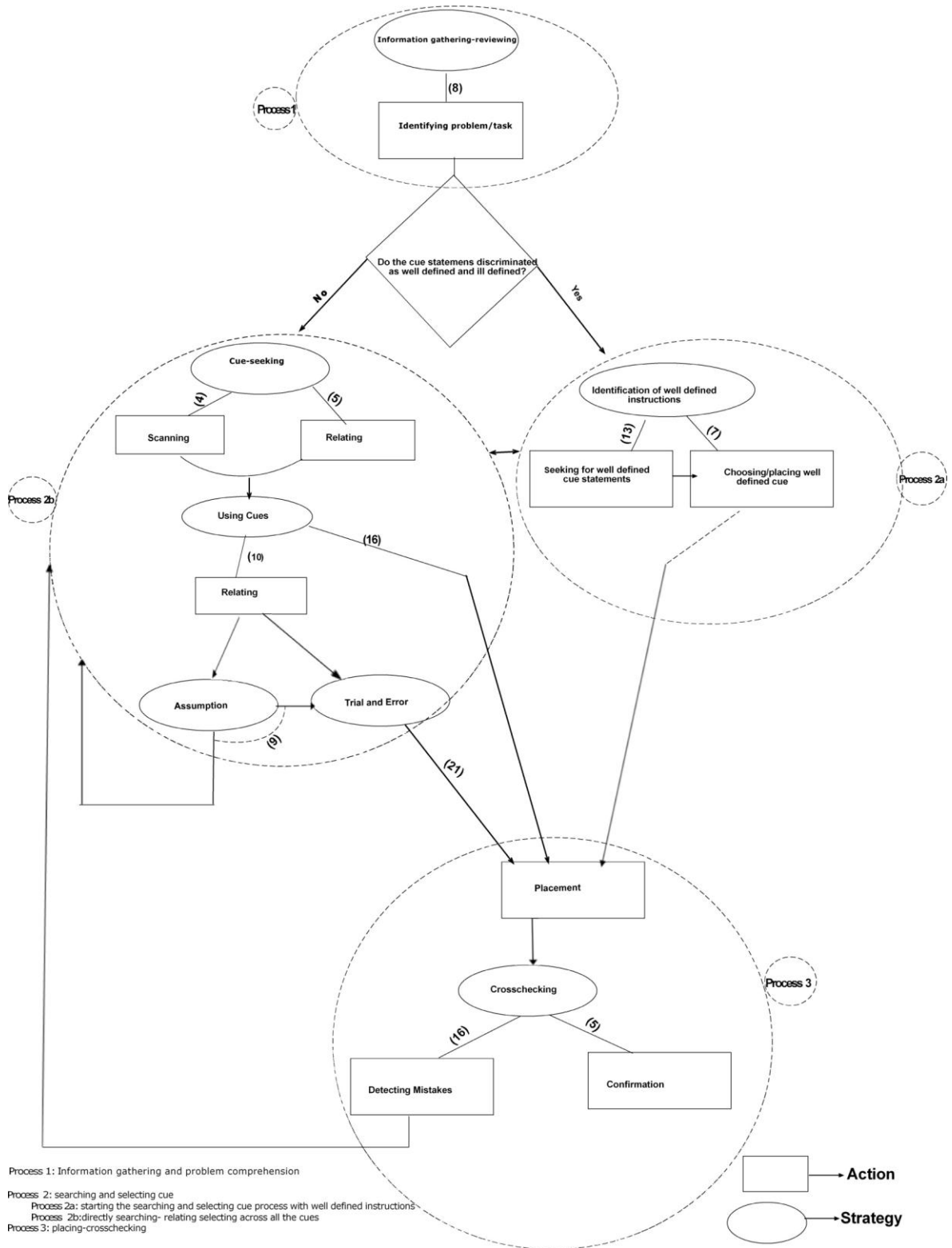


Figure 3. Complex Task Performing Process

As seen in figure 3, three main processes were emerged in complex task performing. The first process was described as "information gathering and problem comprehension" process with the use of *information gathering-reviewing* strategy. Second process was the "searching and selecting cue" process, which is divided into two sub-processes: 1) "starting a searching and selecting cue process with well defined instructions" with the use of *identification well-defined instructions* strategy; 2) "directly searching- relating selecting across all the cues" process with the use of *cue-seeking, using cues, assumption and trial error* strategies. Individuals started with one of the sub processes, but sometimes switched between them. The third process was labeled as "placing-crosschecking" process with *crosschecking* strategy.

Process 1: Information Gathering and Problem Comprehension

Information gathering-reviewing strategy

By this strategy, participants read the given rules or other task related things i.e cues, information items etc. to understand what they were required to do and to comprehend problem logic not taking much action. This cognitive process occurred generally at the first 0.00-1.30 minutes after task started. This process is followed with identifying task/problem action. Example statements were presented below from this process that reflects how the participants verbalized he/she used this strategy and attempted to identify problem/task:

P1: *"Here I mused on solution of the task looking the cues as German's car, English..... At first, I did not already do too much thing because I tried to comprehend the logic of the problem. I focused on the rules"*

P2: *"In the first place I read the givens and look over task components. Then I tried to understand what there were in the cues. And I looked over other givens, information boxes at the right..."*

P4: *"Here I am checking the cues to see what they are standing for. I tried to memorize. Then I looked to the drag and drop information boxes. I realized...."*

"Identifying the task/problem" action by the "information gathering-reviewing strategy" was articulated 8 times by three of the participants. P1 used this strategy four times, P2 used two times and P4 also used two times along the task solution process.

As seen from above example statements participants generally take a look at to the givens to them, read the cues to comprehend and investigate the other given information items i.e. information boxes, matrix field, rules... Only P1 re-reviewed the rules more than one times to remind himself directives of task.

Derived from the information gathering-reviewing strategy process, fixation durations on area of interests of also support verbal report of participants (Table 2).

Table 2. Fixation Durations and Total Duration Times in Seconds per Participant for Information Gathering-Reviewing Strategy

	Cue field	Placement matrix	Rules	Information items	Duration (sec)
P1	38,759	1,749	4,747	7,110	53
P2	6,639	2,179	0,383	4,89	18
P4	16,031	7,029	0,000	6,6	32

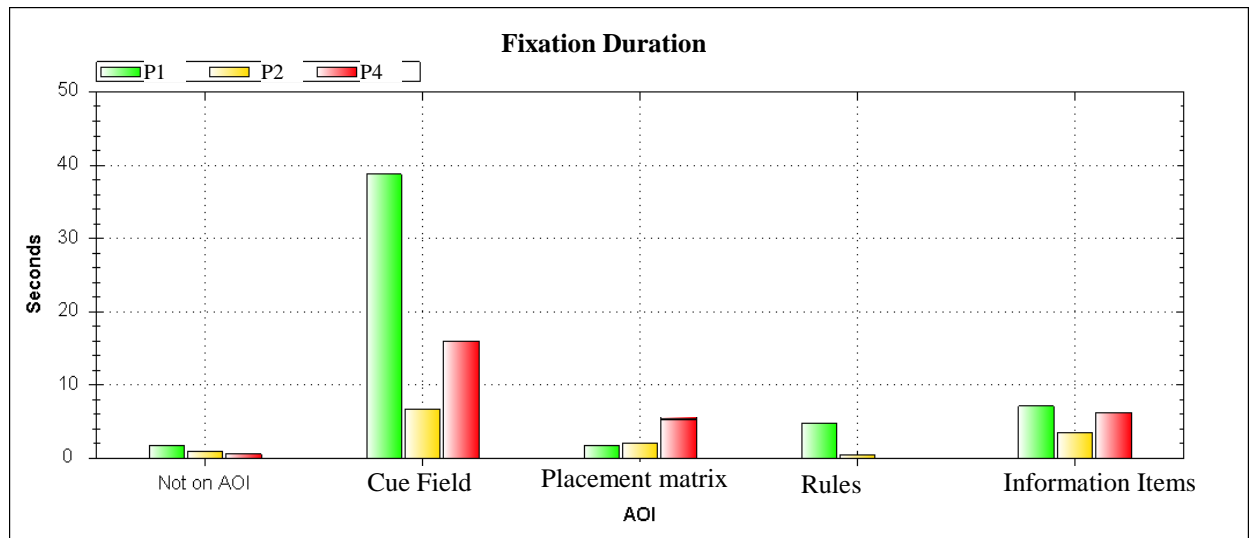


Figure 4. Fixation Duration in Each AOI in Information Gathering-Reviewing Strategy

As seen in Table 2 P1, used information gathering-reviewing strategy for four times, had the longest time (53 sec) for this strategy. P2, who used this strategy for two times, spend 18 sec. and P4 who also used this strategy for two times spent 32 sec. Total fixation duration chart (Figure 4) already shows that P1 had the longest fixation duration following by P4 and P2 had the least fixation duration time for this strategy.

Fixation duration per each AOI in figure 4 shows that the participant mostly fixated on the cue field. Also, individuals' verbal reports were in the support of their eye movements since they stated that firstly they looked at the cues and information items and then read the cues in depth to understand clues. Succeeding the cue field participants second most fixated on information items. However they also reported that since they are attempting to identify task problem, they needed to check embedded information in cues from information item boxes part or taking a glance at those information items. But, since they tried to comprehend cues by reading but only taking a glance to scan at information items, fixation duration on the information items is pretty fewer than the cue field. Placement matrix area and rules area were found to be least fixated on. This can be due to only P1 read the rules but not two other participants and none of the participants not started to place any information.

Apart from these three participants, other two participants did not report they started with this process; they started directly placing information on the matrix with second process.

Process 2: Searching and selecting cue

After the information gathering and problem comprehension process participants started to second process which is the selection process to place information after reading cues. This process divided into two sub-processes: 1) "starting the searching and selecting cue process with well defined instructions" with the use of *identification well-defined instructions* strategy; 2) "directly searching-relating selecting across all the cues" process with the use of *cue-seeking, using cues, assumption and trial error* strategies.

In the second process, two of the participants started the cue searching and selecting process with well defined instructions while other three started directly searching- relating selecting across all the cues. Eye movement related to second process also verified the two different starting strategies. Heatmap belongs to process of four participants' placing first three information item is presented below (Figure 5a, 5b, 6a, 6b)

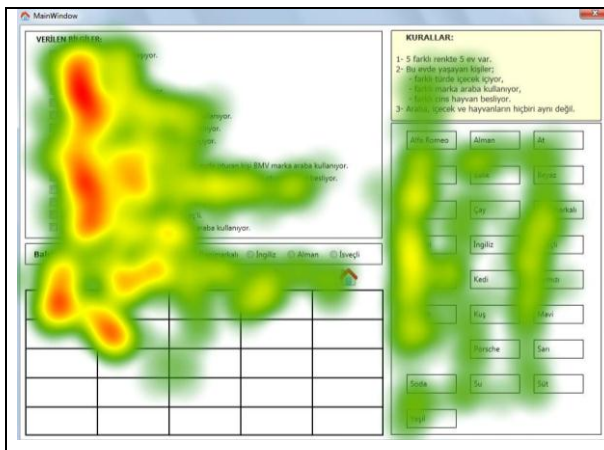


Figure 5a. Process Regard to Placing First Three Information Items Starting with Well Defined Items(P4)

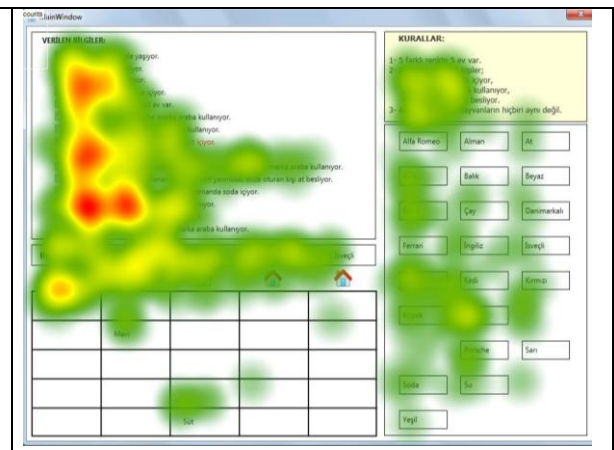


Figure 5b: Process Regard to Placing First Three Information Items Starting with Well Defined Items (P1)

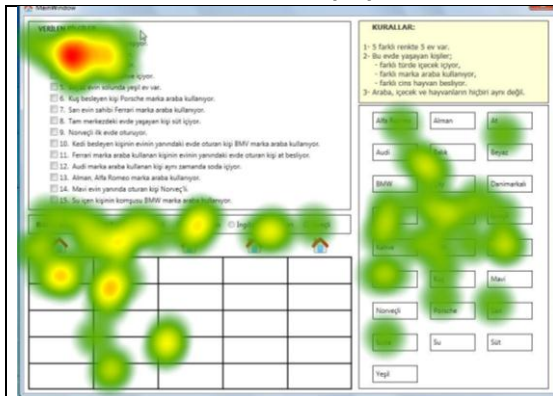


Figure 6a. Process Regard to Placing First Three Information Items Starting without Well Defined Items (P2)

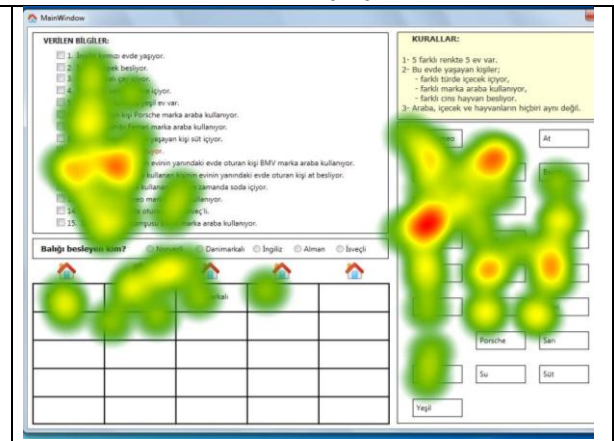


Figure 6b. Process Regard to Placing First Three Information Items Starting without Well Defined Items (P3)

Figure 5a and 5b show the process of two participants who started with well defined instructions and Figure 6a and 6b show the process of two participants who started directly with all the cues without discriminating the well defined or not.

Three information items placed by first two participants (5a, 5b) are being well defined ones; however the first three information items placed by the other two participants (6a, 6b) are the not well defined and placed indefinitely.

As seen in figure 5a and 5b, participants, who started with well defined instruction, focused and fixated mostly on cue field and read all the cue statements to select well defined items among others. They only scanned the information items area to drag selected information box not fixating longer here. One of the participants, P4, being started with well defined instructions reported his/her process as:

"The thing I have attended now is the item which I found a cue, it is the part that I thought it stands me in good stead. That choice. I looked for, how I can replace the value of that choice .

Here it was the first cue (9. item) which I determined as could be useful for me, it was also an item which includes direct and clear a cue statement. I think, at this moment I am looking for the Norwegian to place it on the matrix.

There, I put it to its place with drag and drop and I marked that cue to indicate that it is done.

At that moment, I am looking for an another cue which is direct and exact to place as prior , there. I found an item and this was the item which I decided clearly through the Norwegian, I also put it to its place."

On the other side, as seen in figure 6a, P2 read only first three cue statements to place first three information items without being sure accurateness of this placement. So, the initial cues were the most focused area for that person. Also P3, started without well defined instruction as seen in figure 6b, read firstly the 9th cue (*Norwegian lives in the first house*) which was given in the example demo before the task and placed the information item given in that cue. After that he/she focused on information item boxes to find information related to that he placed (Norwegian-first house) and placed another two information randomly not being accurate (car, beverage...). As a result he/she focused mostly on the information items area but looked over the cues only for reading the 9th cue. So the participants who did not started with well defined instructions focused different area not reading at first all the cues and comprehend them. One of the participants, P3, who did not start with well defined instruction, stated his/her process as:

"I have started to fill the matrix. I put the Norwegian at the first field. I put it at the first field utilizing from the "Norwegian lives in the first house" cue. After that I browse the car brands again in order to find who uses what, which car brand. I entered the all nations first, one by one. I did not act upon any rule, I put all of them being law unto myself. Then, I placed the German into the second column. I placed the Danish into the third column, Sweeden into fourth column and English to the fifth column. After that I looked over "English lives in the red house" cue. I looked "Danish drinks tea" section. Then, utilizing from the "Sweeden feeds dog" cue I placed the dog item under the Sweeden. Utilizing from "Danish drinks tea" cue, I placed the tea item under the Danish..."

Lastly, although P5 also did not start with well defined instructions and placed randomly, he/she was not taken into account in that analysis. Because of unclear process of him, not doing anything at the first 2.5 minute, reading only cues, and did not think aloud in that process.

Process 2a: Searching and selecting cue with well defined instructions process

Identification of well-defined instructions strategy

In this process, participants either identified firstly well defined instructions to place these clearly precise items or searched for other well defined precise item from cues, after placing well defined, to sustain this process.

So, the actions performed with this strategy were determined as "seeking for well defined cue statements" and "choosing/placing well defined cue statements". Some of the examples verbal reports form participants were presented below

P4: "Now, I am looking for a condition between items which could guide me to act in no uncertain terms not by chance.."

Reading through and through, I am seeking which one is useful for me"

P2: " Henceforward, I was looking for exact items to place on matrix and I was placing the indefinite ones at the right side. Because, I thought this is the only way to could get out. Even though I was late for this..."

P5: "at the end, I placed the well defined items on the matrix. I read all the cues again from the beginning."

P3: "I put the Norwegian at the first field. I put it at the first field utilizing from the "Norwegian lives in the first house" cue"

As seen above examples, identifying well defined instructions, participants either selected those and placed or re-searched for other well defined instructions.

Identifying well defined instructions strategy was occurred totally 13 times for "seeking for well defined cue statements" and 7 times for "choosing/placing well defined cue statements".

Process 2b: Directly searching - relating selecting across all the cues

In this process participants used all the cues not discriminating well defined or not, conditional or not conditional. Also, after placing the well defined items and not finding anymore, participants tried to make the relations between cues to continue in this process.

Cue seeking strategy:

This strategy was employed by participants for seeking information among others that facilitates their process, guides to them or helps them to progress, so they can plan the next steps or obtain further data.

By using this strategy participants either *scanned* the information items or *related* the cues with other data to determine next step. So the actions performed by this strategy are determined as scanning and relating.

Two example statements are presented below that show participants scanned for information through the cue seeking strategy:

P2: "Here I reviewed all the cues again, and read again. Thinking that can it be something unnoticed or can I find a new cue?"

P3: "After that I looked to Alfa Romeo car, thinking that is there an information about it, I tried to find it among given cues. Then I take brief look at all of them. Firstly, I looked the animal they feed. Following that, I scanned the car brands, I looked over them."

Another two example statements are presented below that show participant make relations between cues through the cue seeking strategy:

P1: "Just than here I tried to make a relation between cars and beverages. At first I wanted to continue on Audi car model. But after that, since I could not much cue about it I go toward to the BMW and Ferrari models here."

P2: " All I do at that moment was looking for a cue among the data to make a relation. After that I tried make a relation in my own way, thinking that if I put that there, could it fulfill other cue."

However cue seeking strategy was used while in either actions scanning the cues and relating the cues, these two actions are differed from each other. While scanning the cues, individuals did not fixated too long anywhere but rather take a cursory glance, on the other hand while searching the cues for relating they fixated longer on specific cues or information items to make a relation finding a new cue.

Although all participants used this strategy, their eye tracking metrics also signaled different outcomes when scanning and relating the cues.

Table 3 represent the fixation duration per AOI, total duration times, frequency of actions, mean of fixation duration and mean of total durations during the scanning and relating via cue seeking strategy.

Table 3: Fixation Duration and Total Duration (Sec) in Scanning and Relation Actions

	Fixation Duration (sec)					Total Time (sec)	f	Mean	
	AOI				Total fixation duration			Fixation Duration	Total time
	Cue Field	Placement matrix	Information items	Rules					
Cue seeking Relating	73,52	26,8	4,86	0	105.18	111	5	21.036	22,2
Scanning	24,27	2,18	3,17	0	29,62	31	4	7.4	7,75

As seen in Table 3 scanning via cue seeking strategy was occurred 4 times while relating via cue seeking strategy occurred 5 times. Totally 31 second was spent for scanning and 11 second was spent for relating, while the mean time for one scanning action was 7.75 sec. and 22.2 sec. for relating action. Similarly, participants' total fixation duration while scanning via cue seeking strategy was 29,62 sec. and 105.18 sec. for relating via cue seeking strategy. Finally, mean fixation duration time for one scanning action was 7.4 sec. while this mean was 21sec. for relating action. All of these findings indicate that participants spent approximately three times more fixation and spent three times more time while relating cues as compared to scanning them. So it can be suggested that, while making relations, individuals focus more heavily on the task process by making more mental effort than while they scan something taking glance superficially.

Using Cues Strategy

This strategy is used by participants to relate their data with given information in cues without discriminating well defined or not, try to obtain new well defined instructions by identifying the relationship with other cues or to place the cues directly on the matrix with regard to any of read information. So, since participants placed items on the matrix directly with regard to any information in the cues or related their cues with others, "relating" and "placing" were determined the two of action which were performed by this strategy.

An example of participants' relating action with using cues strategy is given below:

P1: "Later on, thinking that a top down approach would be logical, I focused on the cue of where does English live. I read all the cues one by one. After that, I came toward to Norwegian. Here I could not decide on which one should I put first. I attempted to take a look at cues. Eleventh.. That is, the person feed horse who lives next to the house of the Ferrari model car user, ...I mean I tried to match uppers and downs... mostly tried to reason on them at first."

P2: "At that moment, I was mostly attempt to relate green and coffee, since there was a cue as the owner of the green house drink coffee. I was trying to connect this relation. Actually there was a very simple logic of this task. I only need the match given cues according to items on the right side. That is, |||||, for example considering the cue of German uses Alfa Romeo... if I juxtapose the information items of Alfa Romeo and German, afterwards I could find a field on matrix to place them."

An example of participants' placing action with using cues strategy is given below:

P3: "Starting from the point of, the person, who lives next to the house of Ferrari user, feeds horse, I put the horse there,... since German was next to the Norwegian."

P1: "Afterwards I tried make relation between colors and beverages. It was the cue " there is white house next to the green house" which prompted me to placed the white house here. Since green house was drinking coffee I placed the coffee under the green house."

As seen above examples from verbal reports of participants, using the cues they either directly placed information items or attempted to make a relationship between information in the cues. While relating the cues by using the cues occurred 10 times, placing the information utilizing from the cues occurred 16 times.

Assumption strategy

This strategy was used by participants as a method to speculate their next action by utilizing from the given cues, analyzing these cues and defining the relations between those cues and also to inexact hypothesizing or finding solutions by reasoning. In this complex task context, participants employed this strategy to be able to place information items and to speculate the possible placement action which will promote the process. By using this strategy, participants did not directly placed the information items but only made assumptions about the possible placement action. Some of the verbal reports from participants that reflect they used assumption strategy were exemplified below:

P2: "Here I thought the relation of BMW in quite a while. That is, I thought were water and cat under the same or different columns, if the person who lives next to the house of cat feeder, uses BMW car and if the person who is the neighbor of the water drinker uses the BMW? Later, I thought about the fields which I could place those. I mean....could I place water and cat under the same column or must they be placed under different columns."

P4: "After that, again I tried to make a relation with beverages. I thought that blue house owner could drink tea".

Assumption strategy was used totally 9 times. Sometimes participants either made assumptions and then by acting in this assumption placed items by trial and error or after making assumption since they are not sure exactly they returned to seeking information to make exact relations.

Trial and Error Strategy

This strategy was defined as the strategy of making the placement action not being sure about accuracy but only by experience acting in their assumption. Participants used trial and error strategy generally for examining the factual truth or falsity of their assumptions. They placed information items on the matrix not being sure the exact accurateness of their action. So placing is determined as the action that was performed by trial and error strategy.

P1: " In that section I checked all the cues again. Using horse, feeding cat,... that's.... models of cars got my attention. After that there was a cue statement as "Audi model car user also drinks mineral water as well". I thought about that the person who drinks mineral water could be the Norwegian. I totally left my choice to chance. And I dragged the Audi there and thinking that he can also drink mineral water, I dragged the mineral water under Audi".

P3:"After that I put the Ferrari under the Norwegian. And I put it there since only BMW car remained for English,since I thought BMW is more logical, ... to tell the truth I did not placed it so meaningfully."

P5: "And now I started to strive at matching. Here I placed all the nations by chance. After that, I returned to cues and rethought about them."

Trial and error strategy was performed totally 21 times in the study by the five participants.

Process 3: Placing - Crosschecking

In this process, participant placed the information items which they selected after the second process. Placing action was employed by either of three strategies namely identifying well defined instructions, using cues and trial error strategy. One example from verbal reports of participants for each strategy presented below:

Placing by identifying well defined instructions:

P4: "Yes, I found an item which I could benefit. This a well defined and exact cue. This an information which I could place it to its own place by checking. The person who lives in the center house".

Placing by using cues;

P3: "I put the mineral water under the Sweeden based on "the user of Audi drink mineral water" cue.

Placing by trial and error;

P1: "Here I thought that Sweeden could feed dog. Because, no more much animal name remained. And I trust to my chance.

Trial and error strategy was the most used strategy for placing action being performed 21 times, while followed by using cue strategy with the 16 times and the identifying well defined instruction was the least used strategy for placing items with the frequency of 7.

Crosschecking Strategy

After the placing action, individuals mostly applied to examine the accuracy of their processing or right after realizing their mistakes they checked on consistency of their actions with the information at the cues to find error source. This process was performed by the crosschecking strategy. This strategy was defined as the process of checking accuracy of the action by examining the consistency of the given cues and their placements. Participants used crosschecking strategy to correct their error when realized that they made mistake or to control their process until that time.

"Detecting mistakes" and "confirmation" were revealed out as the actions that were performed by crosschecking strategy.

An example statement was presented below that show detecting mistakes by crosschecking:

P1: "I realized that I have made a mistake between cars. I thought about to change the places of Alfa Romeo and Audi, but when I returned to cues I thought this could be a error. But afterwards, when I rethought, it seemed that this was the most logic replacement. I wanted the replace at first here, but when I returned to cues, the error between beverages.....The Audi car user also drinks mineral water .. but BMW is next to the Alfa Romeo, immmm there was a conflicting here..... I thought this would not be correct even I replace the Audi and then I put back both of them to their own places."

P5: I surmised about not to place nations by chance. Returning to cues, I tried to place them again. I endeavored the place correctly. For this reason I undid all the nations, except Norwegian”.

An example statement was presented below that show confirmation of action by crosschecking:

P1: "Not to make a mistake I checked that the Norwegian lives in the first house again and again. Because I was thinking this was the way for me to solution."

P3: "Again, I looked over the Norwegian lives in the first house to check if it was correct."

By crosschecking strategy participant detected mistakes 16 times and confirmed their actions 5 times. This result showed that rather than checking and confirming step by step their process, participants generally detect their mistakes after they realized.

As seen above examples crosschecking strategy was employed by participants only for making sure themselves and verifying themselves by reviewing their progress. On the other side, while they are detecting mistakes they go through various cognitive processes as undo the actions or changing the location of placed items on the matrix, identifying the error source by comparing the new information with old ones or thinking on correcting solution of their errors. So participants spent more time for detecting mistakes as against to confirmation and their eye movement also supported that finding (Table 4).

Table 4: Total fixation duration and total time spent in confirmation and detection mistakes

		Fixation Duration (sec)				Total fixation duration	Total Time (sec)	f	Mean	
		AOI							Fixation duration	Total Time
		Cue Field	Placement matrix	Information items	Rules					
Crosschecking	Confirmation	22,59	6,40	0	0	28,99	40	5	5,78	8
	Detecting Mistakes	147,61	168,19	39,4	0	355,24	415	16	22,2	25,9

As seen in Table 4 confirmation with crosschecking was occurred 5 times while detecting mistakes occurred 16 times. Totally 40 sec was spent for confirmation and 415 sec. was spent for detecting mistakes, while the mean time for one confirmation action was 8 sec. and 25.9 sec. for one detecting mistakes action. Similarly, participants' total fixation duration was 28.9 sec. while confirmation via crosschecking strategy and 355.24 sec. while detecting mistakes via crosschecking strategy. Finally, mean fixation duration for one confirmation action was 5.78 sec. while this mean was 22.2 sec. for one detecting mistake action. All of these results indicate that the participants fixated approximately

four times more while they are detecting mistakes as compared to confirming and spent three times more time while detecting mistakes as compared to confirmation via crosschecking.

Ultimately, totally seven cognitive strategies were derived from the complex task performance of five participants. Apart from the specific processes of these strategies, to examine where the participant mostly carry out the cognitive processes fixation duration per AOI, fixation count and heatmap visual of all the task completion process was obtained (table 5, figure 7).

Table 5: Total fixation count and fixation duration per AOI in general task completion process

	Cue field		Placement Matrix		Rules		Information Items	
	Fixation Count	Fixation Duration	Fixation Count	Fixation Duration	Fixation Count	Fixation Duration	Fixation Count	Fixation Duration
P1	678	215,155	651	209,735	16	5,18	170	48,102
P2	817	312,277	623	209,867	9	2,615	274	89,011
P3	711	259,937	568	171,04	3	0,55	238	66,225
P4	504	234,833	608	196,301	4	3,654	343	102,1
P5	653	366,688	413	143,126	22	10,194	284	90,744
Min	504	215,155	413	143,126	3	0,55	170	48,102
Max	817	366,688	651	209,867	22	10,194	343	102,1
Tot	3363	1388,891	2863	930,069	54	22,192	1309	396,182
Mean	672,6	277,778	572,6	186,014	10,8	4,438	261,8	79,236
SD	113,09	61,602	94,11	28,728	8,10	3,631	63,69	21,733

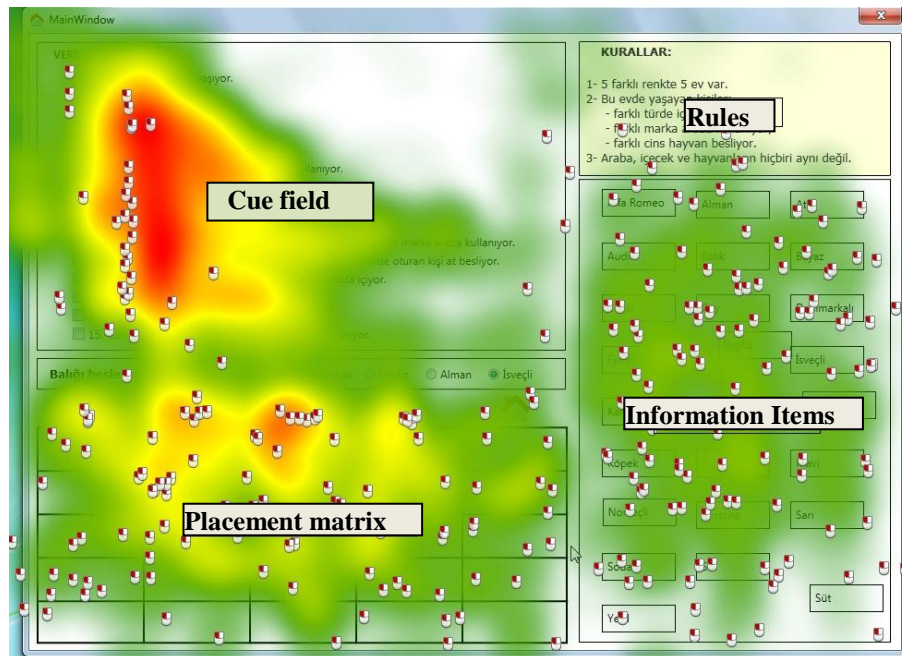


Figure 7. Heatmap of Task Completion Process of Five Participants

As seen in Table 5, participant mostly and longest fixated on the cue field area. Following the cue field, placement matrix field was the second most fixated area by participants. Information items area was at the third rank and rules area was the least fixated area. Heatmap of the general task completion process also supported those statistical data indicating that the cue field and matrix placement was the most heavily focused by the participants.

Discussion

This study investigated the individuals' cognitive processes during a complex task performance. However all of the novice participants failed to complete the task successfully. A cognitive task analysis with cued retrospective think aloud through eye movements was executed to determine the cognitive factors of the failure. As a consequence of analysis, the task process was modeled by cognitive strategies and the actions of these strategies employed by the participants during the task performance. Two of the participants did not use information gathering and reviewing strategy to identify problem/task and started directly solving task. On the other side two of three participants who attempted to identify the task problem before starting solution spent rather a short time in that process while one of them focused longer in this process. Brand-Gruwel, Wopereis & Vermetten (2005) also found that individuals generally start to problem solving process with defining the problem; however, reading the task instructions more often to activate their prior knowledge experts spend more time than the novices on defining the problem. Since, all of the participants failed to complete the task with success in this study, one of the reasons of this failure can be seen as that they did not spend enough time to identify problem and comprehend the task or directly skipping this process.

Some of the participants started to task with well defined instructions while some of them started without discriminating well defined. Nonetheless, all of the participants failed to complete the task successfully regardless of the different starting strategies. This could be because all of the participants, regardless of starting with well defined instructions or not, used trial and error strategy to progress in the process after a while. Time limitation can be the reason, why participants employed to trial and error strategy in the course of time despite they started identifying well defined instructions. Because it was found that participants who started with well defined instructions, focused and fixated more and spent more time to select well defined items among others while the others who started directly with all the cues, fixated shorter and spent less time without discriminating the well defined. Rayner (1978) also stated that longer fixation durations indicate an intensive cognitive processing or having difficulties in information processing.

Trial and error was found to be the most and the identification of well defined instruction is the least employed strategy for placing. Considering the reasons for failure, it has been revealed that trial and error is the most employed strategy when deciding to place information. Users' verbal reports showed that participants used trial and error without reasoning. Similarly, this finding is in line with other research in that novice people tend to work with trial and error strategy (Breslow, 2001) and unsuccessful individuals used random trial and error approaches more frequent than successful individuals (Hackling, 1984)..

Participants employed quite frequently crosschecking strategy but more frequently for detecting mistakes rather than confirmation. Although participants spent more time for detecting mistakes as

against to confirmation, their eye movement also showed that, they fixated approximately four times more while they are detecting mistakes as compared to confirming. So it can be suggested that individuals make much mental effort during the detecting mistakes (Rayner, 1978). Since individual progressed in the task process without verifying their action and spent much time to correct their mistakes which they detected at quite later stages, this can be reason of why they failed to complete the task within the prescribed time. So it can be suggested that, especially in complex learning tasks which include various component and steps that are in interaction with each other, regular feedback must be given to individuals in the process to inform them about their progress in the task. In this way, individuals don't spend too much time and effort to correct their mistakes in the end.

Examining the general task processing areas showed that participants most heavily focused on the cue field and secondly on placement matrix field. However, when this finding is taken into account from the perspective of cognitive processes, these areas of interests are the two fields on which the most heavily cognitive processes are executed. All the participants read the cues continuously, make a relationship between them and compare them to determine the next action. Finding regarding to cognitive strategies of this study also support this result. Because the strategies of the cognitive model i.e. scanning by cue seeking, relating by cue seeking, placing by using cues, discriminating well defined instructions, crosschecking, making assumptions generally and mostly requires the using the cue field and placement matrix. On the other hand, since individuals use information items fields only to drag the information after the cognitive selection process and drop them to the matrix field, not too intensive mental processes executed on it. Lastly, since demo video and example questions with instructions were given to participants to guide them, they did not need to utilize from rules too much. As a result participants did not fixate and focused on information items field and rules field too much. Taking into account this finding from the viewpoint instructional design of learning environments, it can be suggested that determining the most important areas for cognitive processes and make clear instruction and precise information on this areas could help the user to spend less time and less mental effort to progress.

This study showed that although novices employ various cognitive strategies they still remain incapable to perform a complex task successfully under the time pressure. A lack of metacognitive knowledge of novices about cognitive strategies of their own process could be one of the reasons of this finding. Flavell (1979) stated that "cognitive strategies are invoked to make cognitive progress, metacognitive strategies to monitor it". Individuals with high metacognitive knowledge are aware of their own cognitive process reflecting on their task process (Hill and Hannafin (1997) and able to decide where, when and what strategies are likely to be effective in achieving a goal (Flavell, 1979). Also in this study, participant's verbal reports showed that they were not aware their own strategy, i.e while one of the participants was using inductive method to match the information cues with the items, he stated in his verbal report that he was using a deductive method.

Novice people are suggested to adopt a suboptimal strategy and maintain it during the task, not switching between other appropriate strategies (Hill & Hannafin, 1997; Lazonder, 2000). On the other side experts are specified as being faster and better at selecting appropriate strategies, also executing a strategy correctly and switching between strategies swiftly when needed (Allen & McGeorge, 2011; Strobel, & Pan, 2010; Lazonder, 2000; Strube, 1991). Similarly in this study, participants as being novices could not used strategies effectively and could not switch between them correctly or swiftly under limited time. So they mostly used trial and error strategy and even they realized they made mistakes they did not changed their strategy.

Examining the five novice participants' complex task performance process in depth, a common cognitive process model was suggested in this study. However, individual problem solution processes and individual verbal reports showed the various differences within the participants. In further studies, besides making general inferences from the results of small samples, each individual can be examined as a case to show individual differences.

Participants mostly failed in choosing and using the right strategy. Considering the reasons for failure, it has been revealed that trial and error is the most employed strategy when deciding to place information. Users' verbal reports showed that participants used trial and error without reasoning. It can be asserted that, if participants are provided with strategy instruction and raised their awareness about their current strategy by using attention guidance methods, they can become more successful. From this point of view, in the second phase of this study, it is aimed to train participants based on a strategy instruction model and examine their strategy and success during performing complex tasks. By doing so, it is intended to point at the importance of strategy instruction for novices to become successful (experts).

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