Unpacking cognitive skills engaged in web-search: how can log files, eye movements, and cued-retrospective reports help? An in-depth qualitative case study

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Search the Internet with a specific purpose has become an important activity. Educational research informs that a better understanding of the cognitive skills involved in this activity is needed, but it is not clear which research techniques can be used for this purpose. One student performed a web-search task and was registered by three different techniques: log files, eye movements, and cued-retrospective reports. With a qualitative analysis, we attempt to provide a twofold contribution: (1) a thorough analysis about the information retrieved from the three techniques separately, and (2) developing a methodology for integrating the information captured from the three techniques. Results showed that log files and eye movements gave insight into cognitive outcomes of skills, and cued-retrospective delivered self-explanations of cognitive and regulation activities. This integration provided an overall and comprehensive picture of the cognitive skills performed and allowed building a synergism among the information captured from each technique.

Keywords: web-search; information-problem solving; log files; eye movements; cued-retrospective reports; unpacking cognitive skills; Internet; in-depth case study; qualitative; techniques; synergism.

1. Introduction

Searching information on Internet is a key activity in education. Research on Information-problem solving (henceforth, IPS) investigates the process involved when students solve complex cognitive tasks in activities such as: searching, processing, organizing and presenting information from Internet (Brand-Gruwel, Wopereis, and Vermetten, 2009; Eisenberg, and Berkowitz 1990; Gerjets, and Hellenthal-Schorr, 2008; Wilson, 1999).

According to the model proposed by Brand-Gruwel et al. (2009), it is described that students need to master the following five steps in order to successfully solve a digital problem: defining the information problem, searching information on Internet, scanning information, processing information in a deeper way, and organizing and presenting the information found. Furthermore, each step can be subdivided in several cognitive, constituent skills (Brand-Gruwel et al., 2009); i.e., defining the information problem involves the constituent skills of reading the assignment and activating prior knowledge, and the step searching information requires the constituent skills of specifying search terms and selecting a result from a search engine results page (SERP). Furthermore, a set of regulation activities –such as orientation, monitoring, steering, and evaluation– is also required during executing all these skills.

Diverse techniques have already been developed and used to study those different cognitive skills involved when solving problems where processing digital information is crucial. For instance, logging protocols recording the actions made on the computer screen (e.g., Van Deursen, Görzig, Van Delzen, Perik, and Stegeman, 2014), eye-tracking measuring the flow of visual attention (e.g., Mason, Pluchino, and Ariasi, 2014; Jarodzka, Janssen, Kirschner, and Erkens, 2015), and verbal protocols expressing cognitive activities (e.g., Brand-Gruwel et al., 2009; Gerjets, Kammerer, and Werner, 2011). However, each technique provides a partial caption of the cognitive skills involved in IPS; consequently, this shows an incomplete understanding of the entire IPS process. To gain a broader insight of the whole process, an investigation on integrating the information captured from different techniques is required (De Koning, Tabbers, Rikers, and Paas, 2010; Hyönä, 2010). Thus, the aim of the current article is to understand what skills can be unpacked by each technique and to investigate how findings from Log files, Eye movements, and Cued-retrospective reports can be integrated This comprehensive insight would be valuable information in order to design appropriate instructional support to help students to learn from Internet and successfully solve IPS tasks.

1.1. Techniques to unpack cognitive skills underlying information-problem solving

Prior research about cognitive skills engaged in IPS have mainly used the following technique groups: (1) observational techniques, which provide insight into the participants' behaviour during IPS; (2) perceptual process-tracing techniques, which concern perceptual-visual activities that cannot be observed from outside; and (3) reporting techniques, which retrieve information from the participants about their thoughts or opinions.

(1) Observational techniques capture the environment, participants' behaviour and context from an observer's perspective (Van Deursen, 2010), such as field notes or video recordings of a classroom (e.g., Bregman, 2012; Kafai, Feldon, Fields, Giang, and Quintero, 2007). An observational technique to capture onscreen behaviour (e.g., in web-searching) is a protocol of log file data, which allows for a fine-grained analysis of actions taken during IPS (Arroyo and Wolf, 2005).

These overt actions can include search terms used, results selected in a SERP, webpages visited, links selected from a webpage, answers presented in a query, time spent in each action, frequency of each action, etc. Log files can unobtrusively record many participants at the same time. This technique has already been used in many studies on searching for information and evaluating it (e.g., Argelagós and Pifarré, 2012; Gerjets et al., 2011; van Drunen, van den Broek, Spink, and Heffelaar, 2009). In previous studies has been shown that this technique can be used for retrieving information on search strategies (Argelagós and Pifarré, 2016; Makinster, Beghetto, and Plucker, 2002), navigation skills (Catledge, and Pitkow, 1995; van Deursen et al., 2014), information behaviour and information literacy (Spink, Dandy, Mallan, and Butler, 2010; Mason, Junyent, and Tornatora, 2014), and student's learning (Arroyo and Wolf, 2005), among other things. However, a disadvantage of this technique is the inability of accessing participants' covert skills.

(2) Perceptual process-tracing techniques include those that track the eye movements' behaviour made by individuals. Eye movements are registered by an eye-tracking apparatus and provide information on what is visually attended to, in what order, and for how long (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, and van de Weijer, 2011). For instance, eye tracking has been used to analyse the visual exploration of a SERP during web search (Kammerer and Gerjets, 2012; Mason et al., 2014; Şendurur and Yildirim, 2015).

Most of eye tracking research is developed under the eye-mind assumption that states that what the participant is being looked at is also cognitively processed, according with the classical reference of Just and Carpenter (1976). However, in our paper we tried to be the most objective as possible in this tough issue and we only considered eye tracking as a perceptual process-tracing technique that measures visual attention, according with more recent publications (e.g., Holmqvist et al., 2011), that starts to question the relation between eye movements and cognitive activity.

A drawback of the eye-movement technique is that the acquisition or utilisation of eye-tracking apparatus is expensive and time consuming (both in recording and analysing). Moreover, eye movements can only reveal which information was processed and when, but no why (Hyönä, 2010).

(3) Reporting techniques have also been used in IPS research. In this group, the most widely used techniques are concurrent- and retrospective reporting (Van Gog, Kester, Nievelstein, Giesbers, and Paas, 2009). In concurrent reporting, also known as thinking aloud, participants verbalize all their thoughts while they are performing a task (Ericsson and Simon, 1993). For retrospective reporting, participants report the thoughts they had while they were working on a task immediately after task performance. To avoid omitting thoughts during task performance, participants should be prompted with recordings of their task performance including recordings of their actions and eye movements, namely cued-retrospective reports (Hansen, 1991). Reporting techniques allow for valid inferences about the cognitive skills underlying task performance (Van Gog, Paas, Van Merriënboer, and Witte, 2005). Cued-retrospective-report technique has been used in IPS tasks since it does not influence task performance (Schmeck, Opfermann, Van Gog, Paas, and Leutner, 2015; Schwonke, Berthold, and Renkl, 2009).

1.2. The present study – Research questions

Different techniques to understand the cognitive skills involved in solving a digital problem have been developed. However, psychological and educational research has also highlighted that all the techniques to unravel the cognitive skills involved in internet searching and developed so far have affordances and drawbacks to overcome. This means that we easily obtain useful data with one technique but we also lose some important data.

On the other hand, previous research has already considered cued-retrospective reports integrating log files and eye movements as a cue to report cognitive skills involved in solving a task (e.g., Elling, Lentz, and De Jong, 2011; Russell and Oren, 2009). Other studies have combined eye movements and self-reports (e.g., Catrysse, Gijbels, Donche, De Maeyer, Van den Bossche, and Gommers, 2016; Salmerón, Naumann, García, and Fajardo, 2016; Zander, Reichelt, Wetzel, Kämmerer, and Bertel, 2015). These studies analysed each data set separately and collapsed each data set over time. Based on these studies, we provide a twofold contribution to IPS research: (1) a thorough analyses about the information retrieved from the three techniques separately (log files, eye movements, and cued-retrospective reports) over time, and (2) developing a methodology for integrating the information captured from the three techniques; to this methodology we will refer as: combined-techniques information retrieval. This integration would provide an overall picture of the cognitive skills performed by a student during an IPS task.

The two research questions addressed in this study are formulated as it follows: (1) What skills involved in IPS can be unpacked by each of the three techniques? (2) How can information retrieved from each technique be integrated in order to get a better understanding of the IPS process?

2. Methodology

2.1. Case study

One PhD student (fictitiously named Beth) in the field of the Learning Sciences and Technologies (woman; age = 32) participated on a voluntary basis in this study.

The case study methodology is considered a relevant and viable alternative in educational research (Yin, 2006) and has become one of the methodologies most present on Internet environments for teaching and learning (Schrire, 2006; Quandt and De Castilho, 2017; Ylikoski and Kivelä, 2017). In the specific field of IPS, case studies have been widely used (e.g., Barron, 2000; Ge and Land, 2003; MaKinster et al., 2002; Pritchard and Cartwright, 2004). According to Stake (1995) and Yin (2006), a case study is suited for extensive research and in-depth analyses of phenomena, it takes into account the conditions of the context in which they appear and attends to multiple and complementary sources of evidence to identify, describe, and understand the phenomena. In a case study, the generalization is not dependent on statistical generalization, but it is associated with the analytic generalization based on the possibility of inferences that, thanks to the logic of the explanatory reasoning, can be extended to other cases (Yin, 2006).

We adopted the case study methodology because it is the most appropriate way to respond to the research questions formulated in this study, i.e., to illustrate and explain the information retrieved by each technique when a student uses Internet and to articulate the integration of the three techniques. Case study offers a distinctive strategy for examining IPS skills and learning (Barron, 2000), and facilitates discussion about educational guidelines due to the detailed descriptions that student experiences allowed (MaKinster et al., 2002). In addition, we used a one-student case study as it is enough to draw strong conclusions and educational implications for instruction, since students from different populations all perform the IPS steps and skills presented above (Brand-Gruwel et al., 2009).

2.2. Materials and apparatus

2.2.1. Information-problem environment

A science web-based IPS task about the likelihood of life on Mars was designed and the student had to search for information on Internet to perform the task. This task consisted of several fact-finding items (i.e., diameter of Mars, distance from Earth to Mars) and information-gathering items (i.e., climate on Mars, channels of Mars) (Jonassen, 2000).

2.2.2. Data recording equipment

Eye movements were recorded with a Tobii 1750 remote eye-movement system with temporal resolution of 50 Hz, and analysed with Tobii Studio software (www.tobii.com). Reporting data was recorded by the same software using a standard microphone attached to the stimulus PC. Furthermore, this equipment also captured a screen recording, which was later used for log file analysis.

2.3. Procedure

To perform the above mentioned web-based task, Beth was engaged to choose one item among the several items available. The student chose the following information-gathering item: channels of Mars, and she took 2 minutes and 12 seconds to solve it. This task is representative of the whole IPS process because, for its resolution, the student had to perform the four IPS steps with their constituent skills, included in the model of Brand-Gruwel et al. (2009): defining the problem, searching information, scanning and processing information, and organizing and presenting the information.

The three techniques were used to capture the IPS process. During task performance, log files were captured and eye movements were tracked. Afterwards, the student reported her thoughts while reviewing recordings of her overt actions and eye movements (log files with eye movements were shown at 75% of the speed).

2.4. Data analysis

2.4.1. Log-file data

Data obtained from screen recordings were transcribed and coded through a coding scheme based on the IPS model of Brand-Gruwel et al. (2009). This coding scheme consists of three types of codes: (1) IPS steps, (2) constituent skills, and (3) task performance.

(1) IPS steps. “Defining the problem”, “Searching for information”, “Scanning and processing information” and “Organizing and presenting the information” (see Table 1). For each step, duration and frequencies were calculated.

-------Table 1. Coding scheme of IPS steps (log-file technique). -------

2) Constituent skills. In the step “Searching for information”, we considered the next two constituent skills: “Typing search terms” and “Selecting results from a SERP”. The information gathered with these two skills, also details its duration and its frequency.

(3) Task performance. The answers given by Beth to solve the IPS task were also collected and classified. Answers could be classified into fact-finding answers (i.e., a fact, a number, or information that could be easily copied from a webpage) or information-gathering answers (information that requires a personal elaboration before presenting it as a solution of the problem) (Jonassen, 2000).

Reliability issues of log-file data were considered, including IPS steps, constituent skills, and task performance; the interrater reliability of two independent raters reached k=.94.

2.4.2. Eye-movement data

Data analyses provided information on the attention allocation across (1) the task webpage, and (2) the webpages visited on Internet.

(1) The task webpage is where the student defined the problem to be solved and presented/organized the information found on Internet. This task webpage was divided into four areas of interest (AOI) based on the IPS steps as defined by Brand-Gruwel et al (2009): “navigation”, “defining the problem”, “defining / presenting information: fact-finding” and “defining / presenting information: gathering”.

For each AOI, the following eye-movement parameters were calculated:

- Time from entering the webpage until the student fixates on the specific area for the first time. This shows which area was attended first and which last.
- Duration of all fixations within each area. This shows which area was attended most. Total fixation durations were calculated on the task webpage according to the AOIs. Values were calculated anew each time the webpage was re-visited.

(2) The webpages visited on Internet. In order to compare the different webpages visited (which include: search engine webpages, SERPs, and other Internet webpages), all webpages were divided into an AOI grid of size 10 (Figure 1). Setting AOIs in this way allows inferring to what extend a webpage was consulted. In that, AOI 1 stands for a very superficial processing of the webpage’s content. When the student looked only at this AOI, she had only a very superficial impression of a webpage (e.g., only its logo or title). AOI 2 represents a less shallow processing, and AOI 3, a more detailed consulting of the information given on the webpage. AOI 4 covers all parts of a webpage that only could be read when the student scrolled down. When doing that, the

student consulted large parts of a webpage. Hence, visiting this AOI stands for an in-depth processing of the information given on this webpage.

-------Figure 1. Spatial division into four types of areas of interest of all webpages consulted during the task (http://nasa.gov/worldbook/marsworldbook.html). -------

A fixation was detected by a velocity-based fixation detection algorithm from Tobii (ClearView filter, see www.tobii.com) and the according thresholds were set at 100 ms and 30 pixels.

Each webpage consulted in solving the task was analysed separately.

2.4.3. Cued-retrospective-report data

Cued-retrospective-report data of Beth was transcribed verbatim and each utterance (i.e., one sentence) was coded through a coding scheme based on the IPS steps and constituent skills (Brand-Gruwel et al., 2009; Walraven, Brand-Gruwel, and Boshuizen, 2009). The scoring system itself consisted of three types of categories:

(1) IPS steps (see Table 2).

(2) Constituent skills. Each step contains several unique constituent skills; therefore, when one skill belongs to a step, it cannot belong to another one (see table 2).

-------Table 2. Coding scheme of IPS steps and constituent skills (cued-retrospective-report technique). -------

(3) Regulation activities. This category refers to an appropriate supervision of one's own performance and decisions (Brand-Gruwel et al., 2009). Regulation activities are not exclusive and they can be found in each IPS step.

Reliability issues of cued-retrospective-report data were also considered, including IPS steps, constituent skills, and regulation activities; the inter-rater reliability of two independent raters reached k=.88.

2.5. Phases and details of the data analysis

The data analysis procedure to combine the data retrieved by the three techniques consisted in two main phases:

(1) The first phase involved displaying the IPS steps performed by the student, with the help of the rawer information retrieved from log-file technique, which was the order of the IPS steps followed by the student (see the "IPS steps" of Figure 2).

(2) In this basis, each IPS step was analysed separately and zoomed. In these steps, the contribution of each technique was placed graphically next to the others puzzle-like. For instance, as regards the IPS step "defining the problem", we collected the contribution of the log file, which consisted in the time devoted to this step (see Figure 2). Then, we took the information retrieved from the eye movements: time invested in each skill (see first column of "task webpage" of Figure 3, which was transformed in a more readable graphic) and viewing order over time in task webpage (see "first visit" of Figure 4). Finally, we added the contribution retrieved from the cued-retrospective reports (see first column of Figure 5). This process was similar to puzzle-solving and the result was like a re-construction of the real situation (see the "1st arrow" in Figure 7), which posteriorly was explained in writing to make more understandable what happened during this step, "defining the problem".

The same process was conducted for the other IPS steps, and the product was similar to a puzzle in which each step and the constituent skills executed were deployed (see Figure 7 and section 3.4).

3. Results

3.1. Log-file technique

Figure 2 shows a sequential representation where Beth executed the different IPS steps, constituent skills, and task performance. The numbers in the graphic indicate the order in which the steps were performed. In this case, the first step performed by Beth was "defining the problem". Then, she searched for information and typed the search terms: Mars. Next, Beth accessed a webpage to scan and process the information. At a certain moment, she consulted the demand, performing again the IPS step "defining the problem", and went back to the webpage. Finally, she answered the task by typing a correct information-gathering answer about channels of Mars. This task lasted 2 minutes and 12 seconds.

-------Figure 2. Task performed by Beth: IPS steps, constituent skills, and task performance, in seconds (log-file technique). -------

3.2. Eye-movement technique

Figure 3 shows the viewing pattern throughout the task. The task webpage (i.e., the webpage in which the student defines the problem and organizes-presents the information) is shown in coloured columns, while the other visited webpages (i.e., webpages in which the student searches and scans-processes the information) are shown in grey-colours. Each column corresponds to one singular visit of a given webpage and hence, the amount of fixation duration is given in a percentage value.

As shown in the legend, Beth only attended to "navigation" AOI at the beginning of this task. The fixation duration attended to "defining problem" AOI, varies across the task flow. The viewing pattern is clearly dominated by attention towards "defining / presenting information: gathering". For the other webpages, the amount of darkness is related to the level of processing the webpage: the darker the column, the more in depth the webpage was processed; the lighter the column, less webpage processing. From the diagram, it can clearly be seen how this viewing pattern varies over time.

-------Figure 3. Beth's viewing pattern over time in the task (eye-movement technique). On the horizontal axis, all webpages that Beth visited are shown over time (i.e., first she visited the task webpage, then the search engine webpage, etc.). On the vertical axis, the amount of time she spent looking at each part of the webpage is shown in % of total viewing time (i.e., on her first visit to the task webpage, she spent 14% on the navigation area; 27% on the 'defining problem' area; 37% on 'organizing/presenting info: fact finding'; and 22% on 'organizing/presenting info: gathering').-------

Furthermore, Figure 4 depicts the order in which Beth approached this task across time. During the first visit, the student first looked at "defining problem" AOI, then at "defining / presenting information" AOI and back to "defining problem" AOI. Next, she looked back and forth in "defining / presenting information" AOI, ending in the "navigation" AOI. During her last visit, Beth started in "defining / presenting information" AOI, going then to "defining problem" AOI and back to "defining / presenting information" AOI.

-------Figure 4. Beth's viewing order over time in task webpage (eye-movement technique). -------

3.3. Cued-retrospective-report technique

Figure 5 shows Beth's follow-up utterances executed along the task. Each IPS step contains several constituent skills' utterances and also regulation utterances. For instance, during the execution of the IPS step "defining the problem", Beth executed a series of utterances which correspond to the following constituent skills and regulation activities, in the following order: analysing the task, determining the information needed, reading the task, determining again the information needed, reading the task once more, regulating the process, reading the task, determining the information needed to solve the problem, and finally reading the task again. After that, she executed the IPS step of “searching for information”, and so successively.

-------Figure 5. Beth’s follow-up utterances regarding the IPS steps, constituent skills, and regulation activities (cued-retrospective-report technique).-------

In addition, Figure 6 presents the proportion between the IPS skills (in which constituent skills are included), regulation activities, and no-code utterances. No-code utterances are referred to those in which the student did not give enough information about the skill performed (for instance: “I don’t remember what I was doing here”). This new category was added a posteriori, after the data analysis.

-------Figure 6. Proportion of IPS steps and constituent skills, regulation activities, and no-code utterances (cued-retrospective-report technique). -------

3.4. Integration of the three process-tracing techniques: the combined-techniques information retrieval methodology

In the previous result sections we have shown the information retrieved from each technique. The second main purpose of this study is to integrate the information captured from the three techniques to gain a better understanding of the IPS process. To pursue this objective, in this section we will present the methodology we used and named combined-techniques information retrieval.

-------Figure 7. Combined-techniques information retrieval--------

As introduced in section 2.5, we have represented this methodology in Figure 7. The first phase was to display the IPS steps performed by the student, with the help of the information retrieved from log-file technique. We have represented this information in the centre of Figure 7, and this phase is the general graphical representation of the student's IPS process (cfr. Figure 2). In our case study, this first phase shows Beth performing the four IPS steps.

The second phase of the combined-techniques information retrieval methodology was to unpack the cognitive skills developed in each IPS step. In order to attain the unpacking procedure, we used the information retrieved from the three techniques and we have zoomed each IPS step in Figure 7. Thus, the 1st arrow of Figure 7 focuses on the first time the student is defining the problem, the 2nd refers to searching for information, the 3rd concerns scanning and processing information, and the 4th is about organizing and presenting information. In the following paragraphs, a detailed description is given about how we have combined the information retrieved from the three techniques in these zoomed areas.

1st arrow (Figure 7). Log files provided the information of the IPS step performed during "defining the problem" which lasted 36 seconds, since the student opened the task to analyse the demand until she opened an Internet search engine to search information in order to solve the demand. Eye movements supplied the information of the viewing order over time and, in our case study, Beth first looked at "defining problem", then "defining / presenting information", and finally "navigation". The percentage of time spent on each step is also shown as it follows: 59% in "defining / presenting information", 27% in "defining problem", and 14% in "navigation". Cued-retrospective reports provided the follow-up utterances about the constituent skills performed, such as analysing the task, determining the information needed, reading the task, and regulation.

This methodology allows us to “re-build” and understand the student’s cognitive skills displayed to solve the IPS task. In our case study, the IPs step of defining the problem lasted 36 seconds in total. During this time, Beth first analysed the task during 10 seconds (27% of the time). Secondly, she read the task required to be solved. In order to do so, she alternated three constituent skills: analysing the task, reading the task, determining what information was needed to solve the problem; and towards the end, she regulated her own performance. This second period lasted 21 seconds (59% of the time). Finally, she went to the navigation area where she spent 5 seconds (14% of the time) to initiate the following step: search for information.

2nd arrow (Figure 7). Beth needed 54 seconds for searching information on Internet. During the first 8 seconds, while regulating her own performance, she typed the search terms “mars” in the search engine; in terms of reading, the level of processing the page was low. After that, according to the information retrieved from the log-file technique, she analysed the SERP during 46 seconds. Before choosing the result and regulating her process, she assessed several results without explaining the criteria she paid attention to and assessed a result according to its reliability. The level of processing this page was slightly deeper this time as she looked at AOIs 3 and 4 during 9 seconds (aprox. 20% of the total time) according to the eye-movement technique.

3rd arrow (Figure 7). The third zoomed area focused on the IPS step “scanning and processing information” during which Beth invested 26 seconds in total. In this time, she looked at the webpage and read it in a low level of processing, only scanning following sentences and trying to find specific information about Mars. While reading, the student analysed the content and regulated her own performance.

4th arrow (Figure 7). Beth organized and presented the information found on Internet for 16 seconds. Eye-movement technique informs that most of this time (98%) she looked at the area of "defining / presenting information". Cued-retrospective reports and log files detail this action and we learn that she looked up the information needed first. After that, she typed the word "present" in one of the boxes of the concept map to be filled with channels on Mars. Then, she executed regulation activities in order to know what step to follow next.

4. Discussion and conclusion

The main objectives of this study were, on one hand, to unpack cognitive skills, through analysing the information that log files, eye movements and cued-retrospective reports can provide, and, on the other hand, to present the combined-techniques information retrieval methodology in which data retrieved from each technique is combined to get a deeper insight into the cognitive skills of an IPS task. Next, we will address both research questions and highlight considerations of each technique that could be applied in further research and instructional design.

Log files provide information on all overt activity on the computer screen, which gives insight into outcomes of cognitive skills. Eye movements provide information on visual and attentional processes, contributing to a fine-grained insight into which exact areas on the screen were attended to, for how long, and in which order. Hence, this data allows drawing conclusions on cognitive skills to a certain extent. Cued-retrospective reports include utterances about thoughts and actions performed. Figure 8 shows a graphic illustration of the manner in which the data retrieved from each technique can contribute to better understand the cognitive skills.

-------Figure 8. Incidence of data retrieved by each technique in cognitive skills.-------

Thus, whereas log files and eye movements give insight into cognitive outcomes of skills, cued-retrospective reports provide self-explanations of cognitive and regulation activities performed. However, whereas log files and eye movements make available objective information (actions on the computer screen, eye movements executed), cued-retrospective reports provide subjective information, since it is the subject who reveals her comprehension of the activity carried out.

Furthermore, it is important to highlight that log-files technique can retrieve all the actions made on the computer screen. Eye-movement technique is able to retrieve almost all the attentional processes performed, taking into consideration that gaze tracking is not totally lineal due to natural actions such as blinking or head motions. Cued-retrospective-report technique cannot inform of each cognitive skill and each regulation activity, but only those verbalised by participants, as explained in the limitations' section.

In the eye-movement technique, the spatial division of the screen into AOIs and the consequent analysis are useful in order to compare the execution of several participants. In this way, it is possible to statistically compare parameters such as fixation duration, fixation frequencies, etc. in each AOI (i.e., Walhout, Brand-Gruwel, Jarodzka, van Dijk, de Groot, and Kirschner, 2015; Meyer, Rasch, and Schnotz, 2010). However, in a qualitative case study like the present, in which every detail during the task performance has been taken into consideration, eye movement combined with log files can provide an unmatched contribution. In this manner, researchers can consider the actions performed on the screen, enhanced by the eye movements. In fact, this video replay was the cue to retrospective-report by the student in this research.

4.1 Samples of technique uses in research

Log files could be a good option when assessing search strategies of students working in a low-tech environment on authentic tasks, i.e., learning curricular contents using Internet access in the classroom (Argelagós and Pifarré, 2016). However, if we need to examine the students' reading level during the webpage scanning and processing the information, eye-movement data would give us better results (Mason et al., 2014). Alternatively, cued-retrospective reports should be a better option if the aim is to understand the regulation activities involved in the resolution of a web-search task (Catrysse et al., 2016).

Moreover, by using the log-file technique, we know which result was selected by the student from a SERP and how much time was invested. Using eye movements, we see if a student paid attention to the title, the description, or/and the URL of the result selected or discarded. Finally, using the cued-retrospective reports technique, we know whether the student evaluated the results according to their usability (the webpage content), their reliability (the author or the sponsor of the webpage), or both (cfr. Walraven et al., 2009). Table 3 outlines some variables to be considered when choosing one or another technique. Thus, deciding which technique is the most appropriate depends on the research questions.

-------Table 3. Variables to be considered when choosing a technique.-------

In addition, the use of different techniques and the integration of them allow a more in-depth insight into the cognitive skills involved when learning from Internet. This is an added value and has theoretical implications for designing instruction, as explained in section 4.3.

4.2 Limitations of each technique

This study also gained insight into the limitations of each recommended technique. The main limitation found of log files was the risk of misinterpreting the students' actions. For instance, log files do not seize the moments when the student is not looking at the computer screen and it does not provide information on whether the student is executing the skill of reading a text or thinking about solving the task.

In the eye-movement technique, interpretation risk may also occur (De Koning et al., 2010; Hyönä, 2010). Another limitation may be the inability to distinguish which skills are being performed when the student is looking at an AOI. For this reason, it is necessary for the researcher to previously consider which constituent skills are related to each AOI. For example, in our study, the designed web-based task required the student to perform the constituent skills related to two different IPS steps –namely: "defining the problem" and "organizing and presenting the information"– while looking at the same AOI. Therefore, it was difficult to code the data regarding the skills of these two steps during the eye-movement data analyses. Another drawback is that researchers should acknowledge the size of the defined AOIs when comparing them, because a wider AOI will be more observed rather than a smaller one. In addition, when an AOI contains an image may be more observed than other AOI without visual content (Boucheix and Lowe, 2010; Mayer, 2010). In order to avoid these kinds of problems, researchers should consider these issues when designing the web-based task used in their study and be aware that in each AOI, which should be equivalent in size and in visual content, a unique IPS step –or even, a unique constituent skill– could be performed.

Regarding cued-retrospective reports, our results showed that, first, some utterances were not possible to code because the student did not give enough information about the skills performed (i.e., “I don’t remember what I was doing here”); secondly, some utterances were quite subjective (i.e., “I think I was...”); thirdly, sometimes the student was not able to verbalise all her performances and she could not give any utterance, even when the researcher frequently said: “Please, keep talking”; fourthly, although the frequencies performing each skill can be retrieved, the time spent cannot be calculated. Thus, cued-retrospective reports cannot provide each cognitive skill and each regulation activity, but only those verbalised by participants. Therefore, as suggested by Van Gog et al. (2009), an accurate selection of the task is needed, to assure it is short enough to be successfully evaluated and, an adequate training for the participants is also necessary so they can verbalise their thoughts as truthful as possible.

4.3 Building a synergy

In this paper, we aimed to develop a methodology for integrating the information captured from the three techniques: log files, eye movements, and cued-retrospective reports; to this methodology we have referred as: combined-techniques information retrieval. This methodology pretends to build a synergism among the information captured from each technique in order to set up a comprehensive picture of the IPS used by a student in order to solve an IPS task. From our point of view, this three-technique synergy allows us to take advantage of the affordances of each one and to mitigate their limitations. For example, the log files’ limitation related to misinterpreting the students’ actions is alleviated by the students’ eye movements. The eye movements’ limitation of performing two different IPS steps while looking at the same AOI is made up by cued-retrospective reports thanks to the student’s explanations. The cued-retrospective reports’ limitations (i.e., forgetting to report thoughts executed during the task, subjectivity and absence of time spent in each process) are mitigated by the overt actions provided by the log files and the attentional processes retrieved from eye movements. Therefore, this synergy gives a better understanding of the IPS process (Kaakinen and Hyönä, 2005). Furthermore, more complex learner profiles can be constructed thanks to the integration of the information retrieved from each technique which may lead to draw out educational implications and conclusions on instructional design.

To conclude, our study provides researchers with new variables to be considered when deciding which technique or techniques are the most appropriate in order to answer the research questions posed in their studies about the IPS process (see Table 3). In this paper, we have developed a valuable methodology that integrates and builds a synergy with the information retrieved from log files, eye movements, and cued-retrospective reports. In our view, the conclusions drawn in this paper can be used to analyse the cognitive skills involved in other kinds of tasks or environments, such as collaborative learning (i.e., Lam, 2017), peer-to-peer interaction (Pellas, 2015), self-regulation learning (Carver and Scheier, 2012), game-based learning (Novak and Johnson, 2012), among other things.

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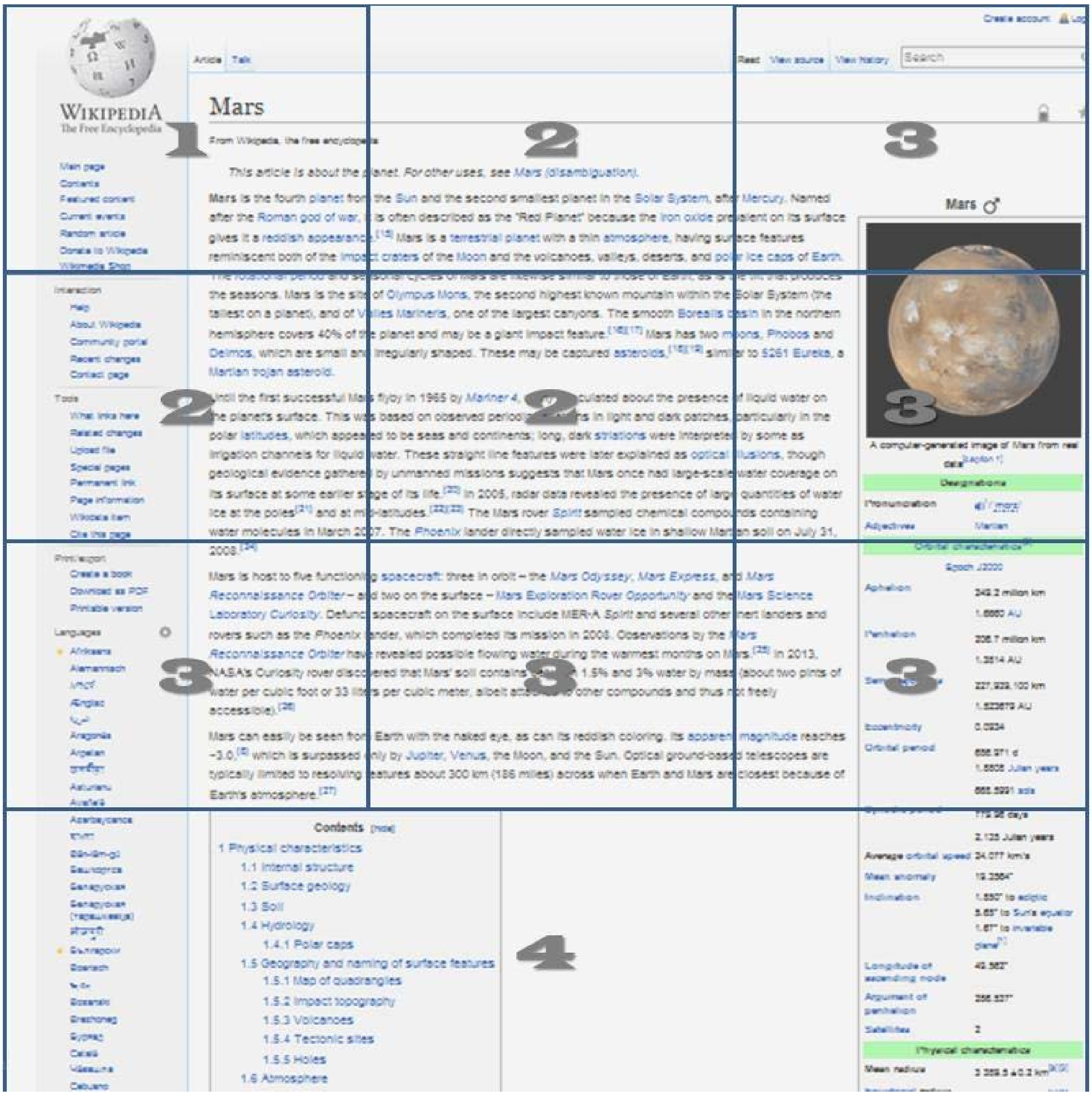


Figure 1

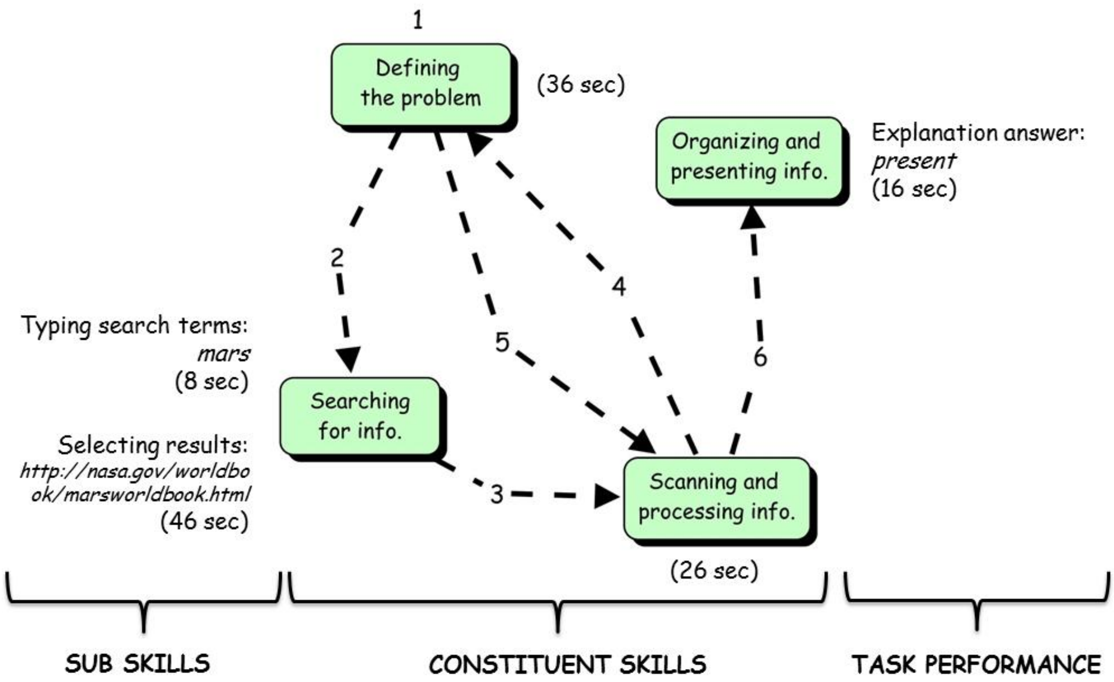

1
Defining
the problem
(36 sec)
Organizing and
presenting info.
Explanation answer:
present
(16 sec)
2
4
5
6
Typing search terms:
mars
(8 sec)
Searching
for info.
Selecting results:
http://nasa.gov/worldbo
ok/marsworldbook.html
(46 sec)
3
Scanning and
processing info.
(26 sec)
SUB SKILLS
CONSTITUENT SKILLS
TASK PERFORMANCE

Figure 2

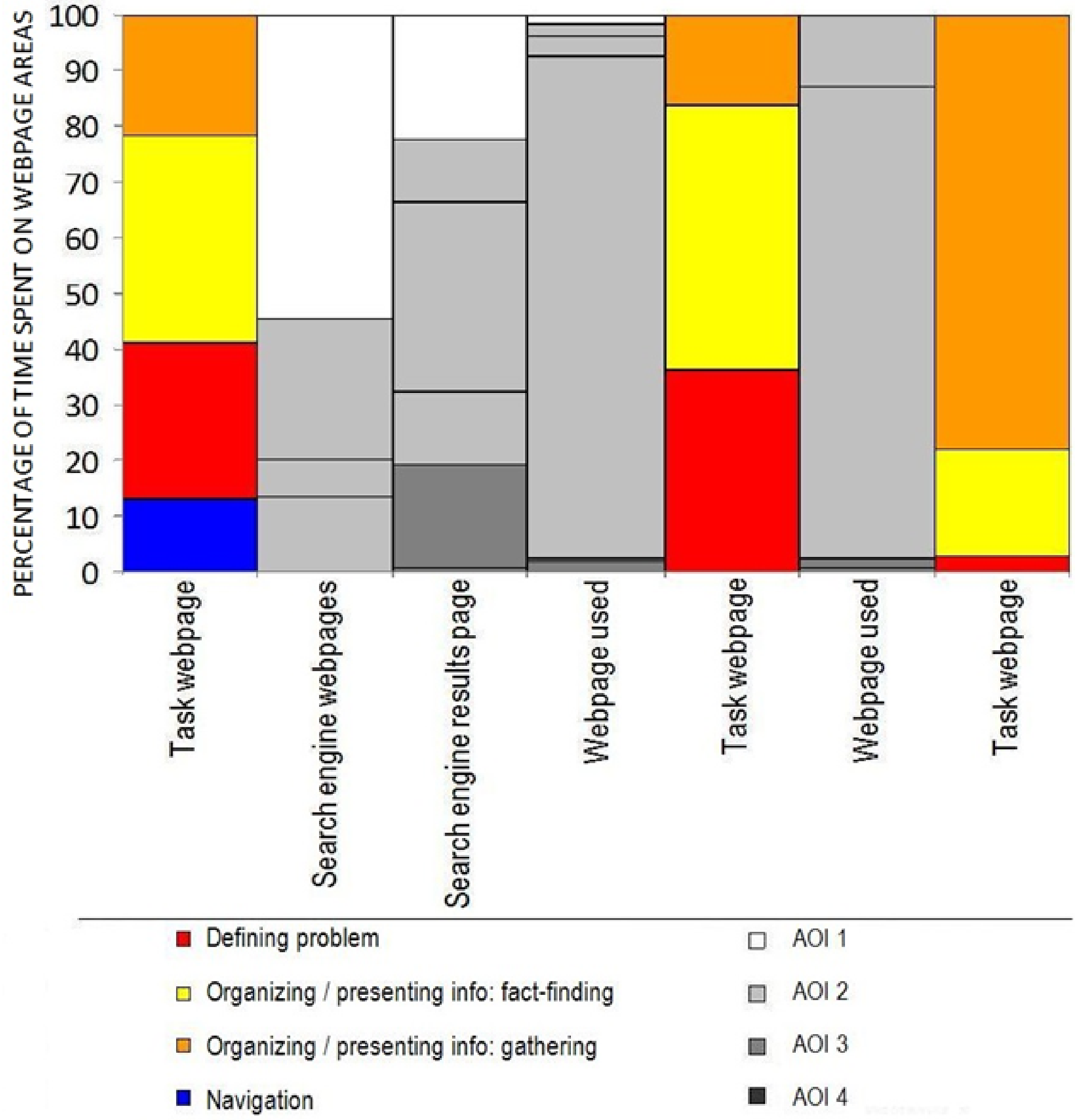

PERCENTAGE OF TIME SPENT ON WEBPAGE AREAS
100
90
80
70
60
50
40
30
20
10
0
Task webpage
Search engine webpages
Search engine results page
Webpage used
Task webpage
Webpage used
Task webpage
Defining problem
Organizing / presenting info: fact-finding
Organizing / presenting info: gathering
Navigation
AOI 1
AOI 2
AOI 3
AOI 4

Figure 3

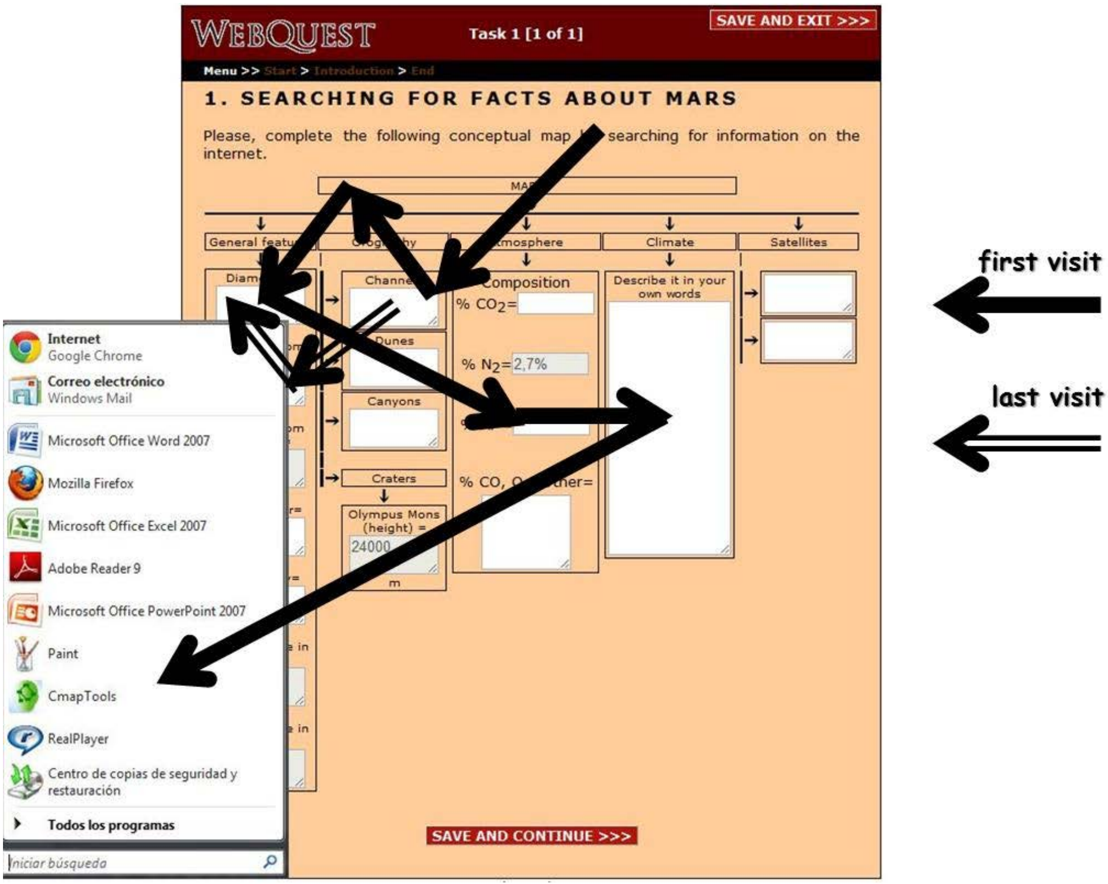

WEBQUEST
Task 1 [1 of 1]
SAVE AND EXIT >>>
Menu >> Start > Introduction > End
1. SEARCHING FOR FACTS ABOUT MARS
Please, complete the following conceptual map by searching for information on the internet.
General features
Climate
Satellites
Composition
% N2= 2,7%
Describe it in your own words
Canyons
Craters
Olympus Mons (height) =
24000
SAVE AND CONTINUE >>>
Internet
Google Chrome
Correo electrónico
Windows Mail
Microsoft Office Word 2007
Mozilla Firefox
Microsoft Office Excel 2007
Adobe Reader 9
Microsoft Office PowerPoint 2007
Paint
CmapTools
RealPlayer
Centro de copias de seguridad y restauración
Todos los programas
Iniciar búsqueda
first visit
last visit

Figure 4

Defining the problem	Searching for info.	Scanning and processing info.	Organizing and presenting info.
Analysing task Info needed Reading task Info needed Reading task Regulation Reading task Info needed Reading task	Regulation Typing search terms Assessing result Assessing result (reliability) Assessing result Regulation Regulation Assessing result Assessing result Assessing result	Analysing the content Scanning, following sentences Regulation	Regulation *<NO CODE>* Typing information-gathering answer Regulation

Figure 5

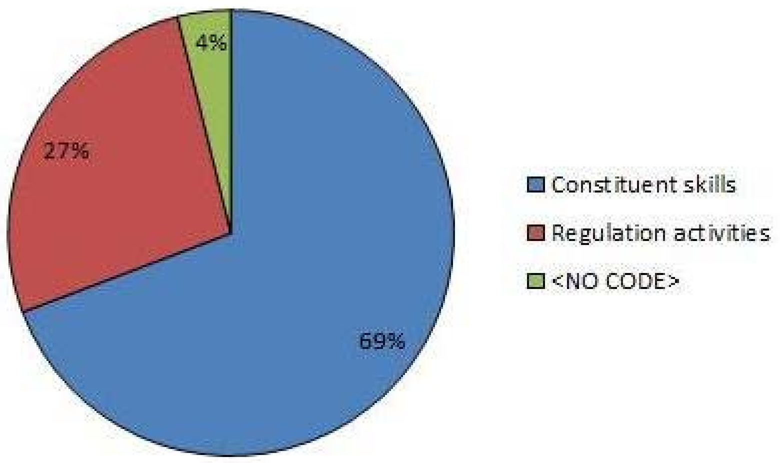
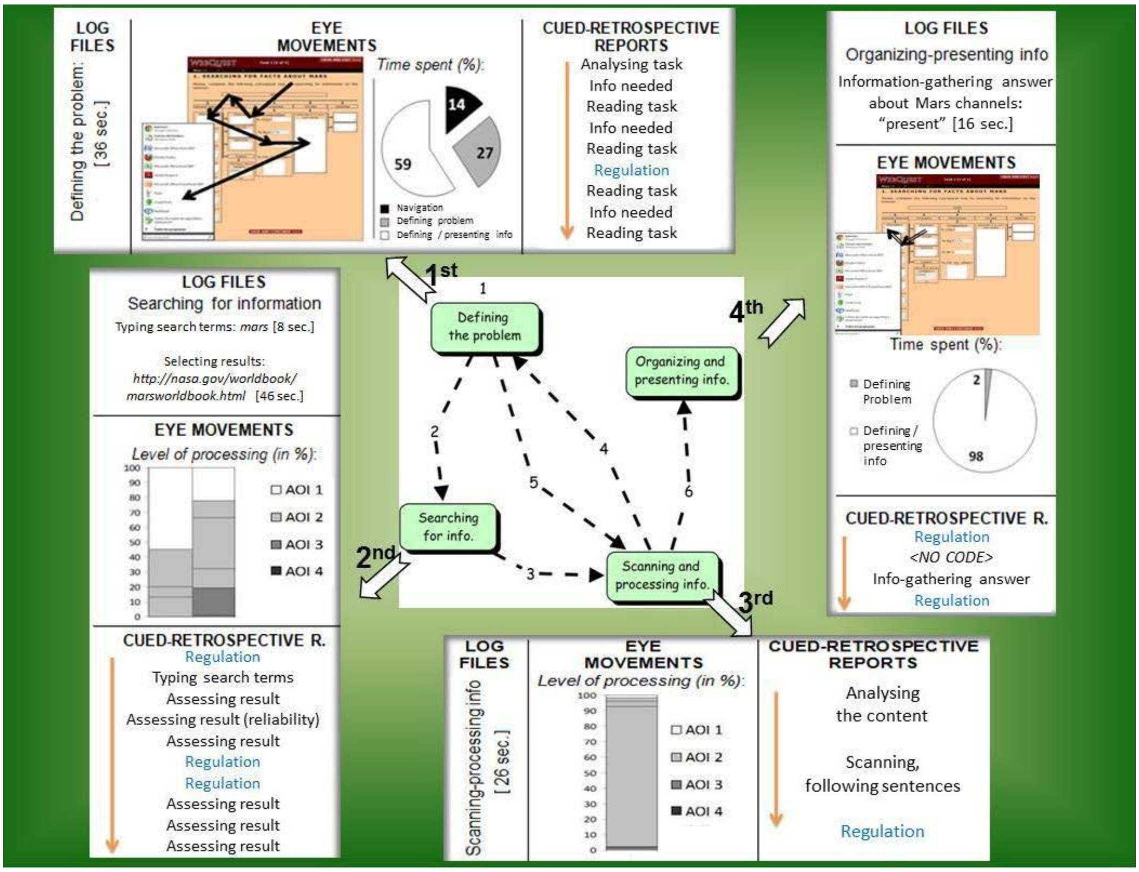


Figure 6



LOG FILES
Defining the problem: [36 sec.]
EYE MOVEMENTS
Time spent (%):
14
27
59
Navigation
Defining problem
Defining / presenting info
CUED-RETROSPECTIVE REPORTS
Analysing task
Info needed
Reading task
Info needed
Reading task
Regulation
Reading task
Info needed
Reading task
1st
1
Defining the problem
Organizing and presenting info.
2
4
5
6
Searching for info.
3
Scanning and processing info.
2nd
3rd
4th
LOG FILES
Searching for information
Typing search terms: mars [8 sec.]
Selecting results: http://nasa.gov/worldbook/marsworldbook.html [46 sec.]
EYE MOVEMENTS
Level of processing (in %):
AOI 1
AOI 2
AOI 3
AOI 4
CUED-RETROSPECTIVE R.
Regulation
Typing search terms
Assessing result
Assessing result (reliability)
Assessing result
Regulation
Regulation
Assessing result
Assessing result
Assessing result
LOG FILES
Organizing-presenting info
Information-gathering answer about Mars channels: "present" [16 sec.]
EYE MOVEMENTS
Time spent (%):
Defining Problem
Defining / presenting info
2
98
CUED-RETROSPECTIVE R.
Regulation
<NO CODE>
Info-gathering answer
Regulation
LOG FILES
Scanning-processing info [26 sec.]
EYE MOVEMENTS
Level of processing (in %):
AOI 1
AOI 2
AOI 3
AOI 4
CUED-RETROSPECTIVE REPORTS
Analysing the content
Scanning, following sentences
Regulation

Figure 7

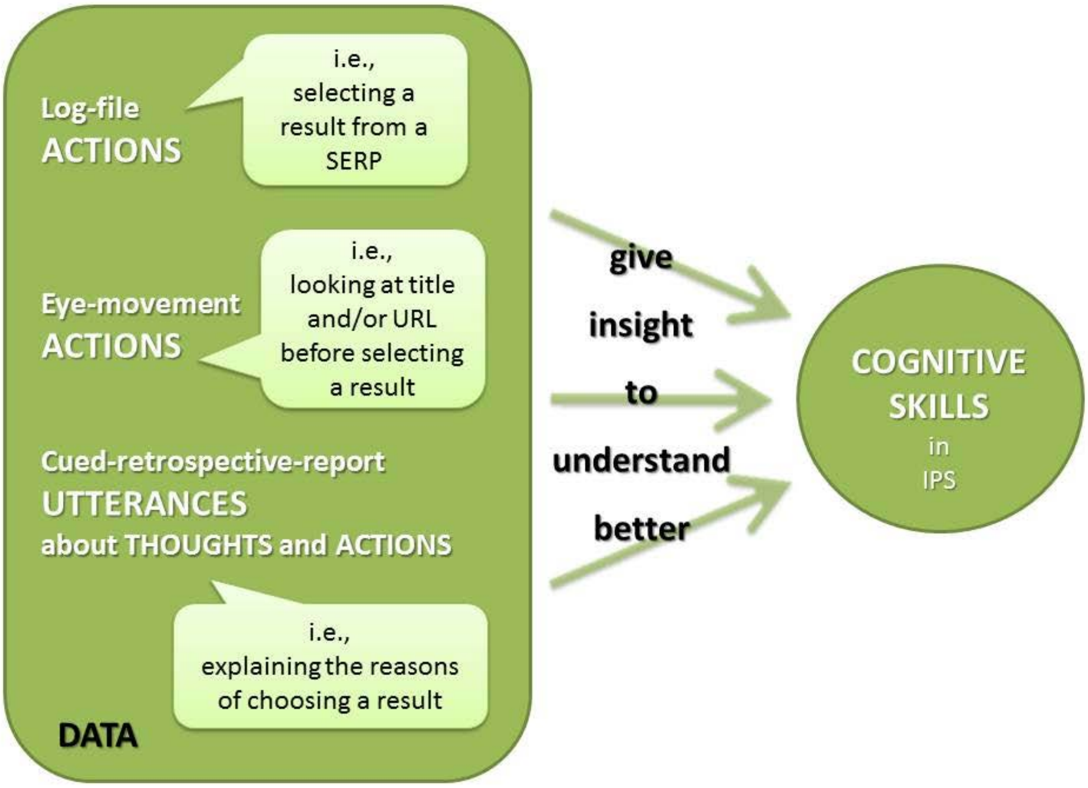

Log-file
ACTIONS
i.e.,
selecting a
result from a
SERP
Eye-movement
ACTIONS
i.e.,
looking at title
and/or URL
before selecting
a result
Cued-retrospective-report
UTTERANCES
about THOUGHTS and ACTIONS
i.e.,
explaining the reasons
of choosing a result
DATA
give
insight
to
understand
better
COGNITIVE
SKILLS
in
IPS

Figure 8

Table 1

IPS steps	Short descriptions
Defining the problem	The student analyses the demand in the IPS task (the computer screen shows the webpage of the assignment), without typing anything.
Searching for information	The student searches for information on the web: accessing a search engine, typing search terms on it, or selecting results from a SERP (the computer screen shows the search engine or the SERP).
Scanning and processing information	The student scans or processes the information on a website.
Organizing and presenting information	The student types an answer on the webpage of the assignment demand.

Table 2

IPS steps	Constituent skills	Description of the actions	Examples of utterances
Defining the problem	Analysing the task	General overview of the task, problem representation	“This is about Mars’ facts”
	Reading task	Read the task webpage	“I was reading the task”
	Info needed	Determine what information is needed to solve the problem	“I had to look for the channels”
Searching for information	Typing search terms	Type search terms on a SERP	“I typed ‘Mars’”
	Assessing result (usability)	Before choosing a result, assess it according to its usability (following the question, topicality, language,…)	“I read the tittle” “I read the summary”
	Assessing result (reliability)	Before choosing a result, assess it according to its reliability (author, attributes, references / links,…)	“I was looking at who was the author of the website”
	Assessing result	Before choosing a result, assess it without mentioning criteria	“I was looking at this website”
Scanning and processing information	Scanning, following words	In a webpage, follow some words, not entire sentences	“I scanned the site…”
	Scanning, following sentences	In a webpage, follow one sentence or noun-phrase	“I scanned some sentences…”
	Reading webpage	Follow more than an entire sentence or noun-phrase	“I read…”
	Analysing the content	Talk about the content read in a webpage	“I thought: they are facts but what I really want are other facts”
Organizing and presenting information	Typing a fact-finding answer	Type an answer, such as a fact, a number, or information that could be easily copied	“I pasted the answer”
	Typing an information-gathering answer	Type an answer, such as information that require a personal elaboration before presenting it as a solution to the problem	“I typed something about channels”
	Elaborating the content	Talk about the content of the written text or the text she is writing	“I wrote: Mars has channels, so channels are present in Mars”

Table 3

Variables	Examples	Technique most recommended*
Context	Low-tech environment	Log file
	Classroom	Log file
	Lab	Eye movements Cued-retrospective reports
Kind of the task	Authentic tasks	Log file Eye movements Cued-retrospective reports
Object of the study	Time invested in each IPS step or skill	Log files
	Frequency of each step or skill	Log files
	Search terms typed in a search engine	Log files
	Evaluation of selected results in a SERP	Eye movements Cued-retrospective reports
	Reading	Eye movements Cued-retrospective reports
	Regulation activities	Cued-retrospective reports

* It is important to highlight that one variable cannot decide which technique should be used, but a combination of the diverse variables can.