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EXPERIENCING PROTOCOL ANALYSIS OF COMPUTER-GUIDED DESIGN TASKS

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1. Introduction

In order to elaborate effective techniques and methods to conduct design tasks and to teach how to perform them, investigating the most effective cognitive approaches holds a paramount importance. Much of the effort devoted by the scientific community to gain a deeper understanding of the cognitive processes intervening during design tasks is addressed at eliciting the reasoning path through Protocol Analysis activities. The investigation of the most relevant issues related to the cognitive aspects through such a methodology consists in the interception of the reasonings followed by individuals and the characterization of such reflective dialogues through suitable taxonomies and frameworks. With the aim of acquiring the most complete comprehension about cognitive processes, the protocol analyses have substantially regarded design tasks carried out with the minimum extent of external boundaries affecting the thinking freedom. As a result, such experiences have extensively observed the behaviours of designers, assigned of a problem to be solved and working from scratch with traditional means (often paper and pen). The circumstances that are generally met when carrying out Protocol Analysis conflict with the growing diffusion of computer applications to support the design activities. The software systems and the media interface result indeed in the limitation of the designer possibilities during the task, causing an alteration of the followed cognitive process. The paper presents an investigation of such relevant issues aimed at providing useful insights about the usage of computer-based systems as viable means to perform Protocol Analysis tasks.

According to these assumptions, Section 2 provides an overview about the documented employment of computers within the investigation of design protocols and explains the reasons for strenghtening its role in the field. Section 3 describes the application of a dialogue-based system, implemented in a computer framework and aimed at analyzing engineering problems for testing the possibility to perform the Protocol Analysis of a sample of generated design discourses. Section 4 discusses the results of such experiment from a methodological point of view and argues about further advantages with respect to traditional protocols. Finally, Section 5 is dedicated to draw the conclusions and illustrate the expected future developments, anticipating some basic requirements for the conception of software applications tailored to support the generation and the analysis of design protocols.

2. An overview on protocol studies and on the current use of computers

2.1 Cognitive processes emerging by protocol studies

The protocol studies are mainly addressed at highlighting which are the most beneficial approaches within design processes and how the behaviours differ according to the experience of the involved subjects.

In this framework, a relevant distinction is assumed to discriminate between problem-driven and solution-oriented approaches. The former involves a major reflection on the features of the problem, resulting in outcomes of higher quality with respect to the alternative approach. The latter, slightly more diffused, is characterized by the tendency of quickly elaborating and confronting feasible solutions, giving rise to more creative results.
A comprehensive review about design approaches, as arising by protocol studies and with a particular focus on expert and outstanding subjects, is performed by [Cross 2004]. Thanks to his research and to following literature contributions sharing and further elaborating the results, it is possible to assess that:

- expert designers do not follow a systematic logic, but tend to skip some design steps;
- both novice and expert designers tend to elaborate few design alternatives and prefer to patch the generated concepts, rather than reconsidering the problem from the beginning; however, when too many alternatives are present, the design process does not lead to good solutions, as well;
- the solution space has to be neither too large, nor too narrow;
- expert designers often move from problem to solution space, considering them “overlapping”;
- intuition is a key capability for good designers.

A relevant contribution is provided by [Atman et al. 2007] to strengthen the mentioned concepts and provide further, perhaps partially contradicting, insights. The survey compares the behaviour and the outcomes of experts with the results obtained in a prior test involving engineering students. The latter are subdivided in “freshman” and “senior” according to the attended year of the University courses. Ultimately, the research has led to the following findings:

- experts dedicate more time in problem scoping activities, i.e. problem definition and information gathering; besides, the last aspect concerns a higher amount of information categories, with a tremendous growth of information demands regarding the problem situation;
- the number of experts’ alternative solutions is much higher;
- quality results of experts are slightly better than those of seniors; the main motivation that has been addressed for the limited improvements is the lack of expertise of the professionals within the treated technical domain;
- the variability of experts’ behaviour is much lower than that of undergraduates; regardless the broad range of disciplinary expertise of the involved people, they typically follow a “cascade” pattern, i.e. a considerable amount of time dedicated to understand the initial problem, the modelling and development of a solution, the refinement and clarification of the problem scope throughout the design process.

As a consequence, it is argued that the competence in a specific domain can be assumed, beyond the individual experience, as a determinant for the success of the design task. From a procedural point of view, experts seem not to follow a systematic and linear sequence of design activities, i.e. from the initial problem formulation and requirements elicitation up to the definition of the solution details. Conversely, they tend to shape simplified patterns to be repeated in an iterative way. The tendency to elaborate tailored cycles confirms the interplay among the experience in design, the maturity of the cognitive processes, the capability of gaining valuable solutions.
Given the previous considerations, each tool or technique tailored to support the design process should be capable to treasure the indications emerging from the analysis of the most beneficial cognitive processes. Additionally, the development of design aids should take into consideration options for self-evaluating their efficacy, by allowing the remote control of the patterns followed by the users, in order to correct further shortcomings, which can potentially lead to poor solutions. Such evolution is expected especially for Computer-Aided design tools, whose domain of application is shifting from the sole detailed design task to the whole innovation pipeline, including product planning and problem solving.

2.2 Procedures to carry out the analysis of design protocols

With the aim of elucidating the methodological aspects of the analyses rather than the outcomes, a recent review classifies, according to several categories, the protocol studies disclosed through authoritative publications [Jiang and Yen 2009]. Among the clusters in which the researches are organized, the taxonomies of design protocol studies are worth of a more accurate discussion.
The implementation of Protocol Analysis shows a predominant employment of think-aloud methods, aimed at examining individual behaviours. Such techniques consist in recording the reasoning about a design task assigned to a fellow, who is urged to speak about and comment the process he/she is following. Whereas a group is involved in the recording, the confront between the designers becomes the object of the so-called conversational protocols. Further on, a minimal amount of design protocols concerns the discussion of the performed project after the task has been accomplished; however, such approach is not considered reliable, due to important aspects that could be neglected in the ex-post speech. Thus, when the objective of the analysis is the investigation of a single person, the think-aloud approach results the most trustworthy. Its main limitations stand in the unnatural behaviour of the designer when facing the problem to be solved, giving rise to experiences whereas the analyzer often encourages the investigated subject to discuss.
The same cited survey points out also the size of the samples of the designers engaged in the Protocol Analyses, revealing that most of the activities have implicated a very limited number of participants. The fact is likely motivated by the difficulties and the time dedicated to prepare the setting for carrying out the investigation and gives rise to the impossibility of producing statistically sound results.
In order to overcome the current limitations, the design tasks carried out through computer applications can be exploited for the purposes of Protocol Analysis, by acting through possibly less intrusive recording means. Furthermore, such a measure can favourably lead to the multiplication of the design experiments available for the subsequent analyses of the cognitive processes.
On the other hand, the need to adapt the individual course of action according to the functioning of computer applications represents a sort of restriction within the display of the design process. Such circumstances plainly determine a constraint hindering the complete autonomy of individuals in performing choices and the possibility of moving freely throughout the design activities. Furthermore, the intrinsic impact of computers in modifying people’s aptitude should be isolated in order to characterize the unrestricted behaviour of designers. Suck task is commonly achieved by the discipline of human-machine interaction and by the means of self-efficacy studies: however, the consideration of such issues goes beyond the purpose of the present paper.

2.3 Current employment of computers in protocol analysis

Up to now, the use of computers has resulted bounded to peculiar facets within the protocol studies of design activities, or, more generally, with reference to the elucidation of cognitive aspects influenced by the presence of machines in the design field. More specifically, the employment of computers has been ultimately disregarded with respect to all those stages aimed at elaborating and refining concepts, such as the functional analysis, the problem structuring, abstraction and solving.
A broad range of knowledge has been formalized with regards to the design activities firstly broached by computer systems, i.e. routine tasks addressed at detailing the developed solutions or sketching activities providing a physical representation of models or ideas. Within such branch of research, protocol studies demonstrate a considerable influence of the employed media in terms of the thinking process and the obtained outputs relevant for the design task [Bilda and Demirkan 2003]. Within the scope of investigating computers impact in design, the role played by ICT for the purposes of communication among several participants has been diffusedly surveyed. The methodological foundations for the execution of Protocol Analysis about computer-mediated collaborative design are laid in [Maher et al. 1996]. Eventually, a recent research [Pourmohamadi and Gero 2011] describes a computer application, namely LINKOgrapher, addressed at standardizing the coding schemes of protocols, which is capable to describe the design process and to ease the representation of the results. However, such system does not help the performing of the Protocol Analysis itself, but just facilitates the organization and the disclosure of the outputs pertaining the design processes.

The limitations recalled in 2.3. justify the poor research carried out to acquire the knowledge about mental processes in design when users employ computerized means. Nevertheless, the authors believe that the proliferation of software applications in the field of design requires a major investigation, allowing to enhance the functionalities of current Computer-Aided systems also in the perspective of conceptual design.
Besides, the results of protocol studies pertaining computerized design tasks could bring to interesting insights, by shedding light on further affinities and mismatches between the results obtained through traditional and software-based activities. With these assumptions, the overall goal of the paper is to verify the possibility of extrapolating the cognitive patterns of users facing design tasks with computer supports.
Beyond the kind of provided aid and the involved phases of the design process supported by existing applications, the possibility of extracting meaningful information strongly depends on the architecture and the interface of the specific Computer-Aided system. The selection of a first application to be analyzed has leant upon a tool for supporting problem analysis and requirements elicitation, underpinned by a dialogue-based system, whereas the user is subjected to questions and reflections about the design task [Becattini et al. 2011]. The pros of such system consist in the involvement of the conceptual design phase, whereas major cognitive efforts are dedicated, and in the implemented step-by-step model that facilitates the mapping of the followed pattern for analyzing the problem, regardless such sequence is consistently affected by the specifications of the software.
The present research, backed by such preliminary experiment, aims at evaluating the expected performances of protocol studies involving design projects guided or, anyway, stimulated by software applications. As an additional result, it illustrates an initial set of requirements for the development of tailored computer instruments for the execution of protocol studies.

2.4 Reflections about the potential role of computers in protocol analysis

As previously remarked, the core objective of a Protocol Analysis activity is the identification of the cognitive processes that bring the most valuable contribution to the solution of problems in design. Nevertheless, even the well-established procedures described in 2.2 present weaknesses in tracking the reflections of designers. For instance, all the “a posteriori” analyses of designers’ behaviour require from 10 up to 1000 times the time of the whole design process [Jiang and Yen 2009]. The main reason behind this time-consuming activity resides in the high degree of human involvement required to carry out the whole procedure, which, as assessed in recent papers, e.g. [Pourmohamadi and Gero 2011], is composed by the following phases:

1. Definition of a coding scheme
2. Recording the activity of designers
3. Transcription of the recordings
4. Segmentation and structuration of the design discourse, according to the coding scheme
5. Analysis of coded protocols
6. Definition of links between desing steps
7. Analysis of the graph collecting such links (linkograph)

With reference to what is claimed by the authors of the last mentioned paper, the LINKOgrapher tool supports the analyst in carrying out the steps 5, 6 and 7. Besides, time-consuming issues, such as transcription of recordings and segmentation/structuration, are still in charge of the analysts.
According to authors’ experience, computers can actually support almost all the phases of such an activity. The task of the analyst, after the definition of the coding scheme and the supervision of the steps, can be limited to the interpretation of protocol results, inferring then insights about the cognitive processes. In such a scenario, the computer is supposed to help in investigating the thread of design thinking by carrying out all those actions in which the reflections of the analyst play no role. Eventually, a computerized tool having such characteristics allows to manage a greater amount of data with minimum efforts and to consequently overcome the current limitations of Protocol Analyses in terms of the small number of designers commonly investigated.
One of the objectives of the present paper is the determination of an initial set of requirements for a computer system contributing to ease the execution of the protocol analysis along not yet supported

phases. Considering that several applications of the LINKOgrapher have been already documented in scientific literature, it is possible to assume that phases from 5 to 7 are already performed with the help of computerized means. Therefore, the attention will be focused on the other phases, from 2 to 4, which can be supported by a computer-aided system, as depicted in Table 1.

Table 1. Initial requirements for a computer-aided tool that supports the analysis of protocols during design tasks

Phase of the process of protocol analysis	Requirements of the computerized tool supporting the phase
Recording the activity of the designer	• Capability to track all the steps carried out by the designer during the design process • Capability to map the duration of each step
Transcription of the recordings	• Capability to translate the recorded activity into a framework suitable for the next phases
Segmentation and structuration according to the coding scheme	• Capability of detecting the steps of the design process • Capability to describe each step according to the characteristics of the coding scheme

3. Experiencing a computer-guided protocol analysis

3.1 Application of a coding scheme for the analysis of protocols to an existing Computer-Aided tool for tackling design tasks

In [Becattini et al. 2011] a reference model has been proposed for the development of Computer-Aided systems aimed at supporting the analysis and the solution of inventive problems, namely non-routine design tasks. In such a context, they also developed an algorithm for the analysis of such problems and embedded it in a web application (OPEN-IT) with the purpose of assisting and coaching designers. The detailed description of the algorithm, available in the above-mentioned reference, is beyond the scope of the present paper, but it is worth to mention its general characteristics with particular regard to its constituting structure.

On the one hand, from a methodological perspective, the algorithm allows to examine the main facets of a problem by structuring the designer's knowledge according to the TRIZ (Russian acronym for Theory of Inventive Problem Solving) body of knowledge, with a step-by-step procedure that follows the logic of the most complete instrument of such theory, proficiently used by many leading industries for solving existing problems and developing innovative products, i.e. ARIZ [Altshuller 1984].

On the other hand, with reference to the framework of the computer system, the tool strongly relies on Human-Computer Interactions (HCI) since all the steps of the algorithm are proposed as questions or communications in textual form. Along the questioning sequence, the designer is asked to type descriptive answers or to click on yes/no buttons (examples are available in Table 3). In the former case, the answers are recorded as variables characterizing a specific feature of the problem; in the latter case, the choice of the user affects the sequence of the following questions. This results in focusing on different facets of the problem, guiding the examination on sets of questions related to, e.g., the removal of undesired effects, the presence of conflicting requirements, the improvement of performances, etc. During the whole analysis, the collected variables are also recalled by the system so that they can be reused to formulate new questions, shaped in an appropriate manner as they appear contextualized in the scope of the problem. Moreover, as briefly described before, the path of investigation is quite adaptable to different situations, since it allows to explore specific facets of the problem. Conversely, the partially predetermined sequence of questions reduces the freedom of the

designer, by forcing his/her thoughts and reflections towards specific directions. In other terms, once the user is focusing on a specific aspect of the problem, the algorithm persists in deepening the examination throughout a set of questions whose articulation is about predefined.
Every design step of the algorithm is recorded and classified according to two classes: path and variables. The first category is determined by the sequence of posed questions, while the second characterizes the answers by linking them to the related feature of the technical system that undergoes the problem.
Table 2 summarizes which peculiarity of the above-described Computer-Aided tool can satisfy the requirements presented in Table 1.

Table 2. Relationships between the requirements of a computerized tool for protocol analysis (Table 1) and the characteristics of the OPEN-IT system for problem analysis developed by the authors

Requirements of the computerized tool for protocol analysis	Characteristics of the OPEN-IT system for problem analysis to fulfil the requirement
Track the step of the designer during the design process	Capability to record the answers of the designer (mouse clicks and pressed keys)
Map the timing with each step of the design process	Missing in the current version, but easily implementable in a next release (The current version just records the sequence of questions and answers)
Translate the recorded activity into a framework suitable for the next phases	Use of "questions and answers" (Q&A) technique
Detect the steps of the design task	Pairs constituted by the posed question and the provided answer
Describe each step according to the characteristics of the coding scheme	Not directly embedded (To be defined)

Answering questions posed by the computer during the analysis of problems is a form of the HCI, which allows to get rid of video recording and transcriptions/translations between medias. Moreover, the ordered record of pairs question/answer directly represents the entire set of steps followed along the thinking process and thus reflecting the designer's behaviour. All the above-mentioned information does not need to be further elaborated by the analyst and can be directly used to desume considerations. For what concerns the capability to map the duration of the steps, it is worth to notice that the elapsed time is currently not measured by the tool, but the time perspective can be taken into account by considering the specific sequence of questions. The description of the design steps, according to a coding scheme is not emebedded into the OPEN-IT platform due to the specific purpose of the web application and because the choice of the coding scheme should remain in charge of the analyst.
Indeed, in order to perform evaluations of the followed approaches, several taxonomies (coding schemes) of design activities have been built, each of them leading to different implications. Among them, a particular consensus has been attributed to the characterization of the reasoning stages in the design process, according to features regarding Functions, Behaviours and Structures (FBS) [Gero and Mc Neill 1998].
In order to enable the computer to automatize the process of characterizing the design step according to a coding scheme, it is required to assign tailored criteria for identifying the appropriate classes based on the selected taxonomy. With the aim of verifying the chance of using Computer-Aided tools for carrying out Protocol Analysis for design processes, the authors decided to characterize every step of the algorithm embedded into the tool for problem analysis, according to the recalled FBS ontology. The match between the steps of the computerized algorithm and the fitting category of the coding scheme, allows to replicate the followed design sequence into graphs depicting the moves throughout the levels of FBS.

3.2 Description of the problem and of the group of designers

In order to collect a set of data on which performing the Protocol Analysis by means of the OPEN-IT platform, a group of 22 people holding a BS or a MS in mechanical engineering was asked to tackle a problem emerged in real industrial context about the handle of a frying pan. In order to ease the comprehension of the exemplary application presented in Section 4, a brief description of the problem follows: "It is required to fasten the panhandle to the main body of a frying pan. Two main design alternatives are available: the use of rivets or the use of a welded joint in combination with a threaded joint. The former presents problems during cleaning, since dirt sticks near the rivets. The latter does not present any cleaning issue, however, the stability of the whole panhandle is quickly jeopardized, because the joints progressively get deformed under the action of heat and food load."

4. Preliminary results

As described in 3, the aim of such exploratory activity is to determine if some phases of the Protocol Analysis process can be automatized by the support of a Computer-Aided tool, without assigning any statistical meaning to the outcomes of this analysis, due to the limited size of the sample.

4.1 Evidences from the analysis of the entire path of design steps

Figure 1 shows, as an exemplary application, five broken lines, each of them representing the approach of a designer tackling the problem of the frying pan. Every design path ranges from peaks and valleys that represent reflections at Functional and Structural level, respectively. Intermediate points refer to design reasonings at Behavioural level.

A preliminary comparison between protocols shows that designers conclude the analysis of a problematic situation with a highly variable number of steps. Moreover designers follow different paths to obtain the complete problem representation according to the TRIZ body of knowledge. On the other hand, it is easy to notice that this kind of analysis allows to recognize several regularities. Their presence is mainly due to the fact that the design discourse is partially constrained, as mentioned in 3.1.

Indeed, the algorithm presents some blocks of questions with a rigid structure and changes are allowed just to focus on different facets of the problem. The two letters labels reported on the lines determine the beginning of blocks of steps characterized by questions related to specific facets of the problem (e.g.: PE represent the block of questions regarding he improvement of performances, NE the removal of undesired effect, etc.). However, the identification of the beginning of logical blocks on each path enables to carry out an in-depth examination of such regularities. Observing the path of the first designer (first line from the top), it is possible to notice that a meaningful part of the protocol has resulted in an iteration: the sequence pertaining to the blocks IS and PE is repeated three times from the beginning. Similar considerations can be also extended to the second protocol and to the last protocol from the top. Furthermore, once regularities of this kind emerge, it is possible to notice small fluctuations as it happens for the second line from the top. The sequence between the blocks IS and PE is repeated two times, but their length differs in those two cases. In such situations it is possible to highlight that the designer lingers over a specific aspect trying to reformulate the problem in an appropriate manner.

At last, even if this kind of analysis goes beyond the scope of present paper, it is worth to highlight that differences between paths, as depicted in Figure 1, show that the complete description of the problematic situation depends on the capability of the user to change its definition from an ill-structured to a well-structured one [Simon 1973], consistently to his/her knowledge about the laws of nature driving the involved phenomena.

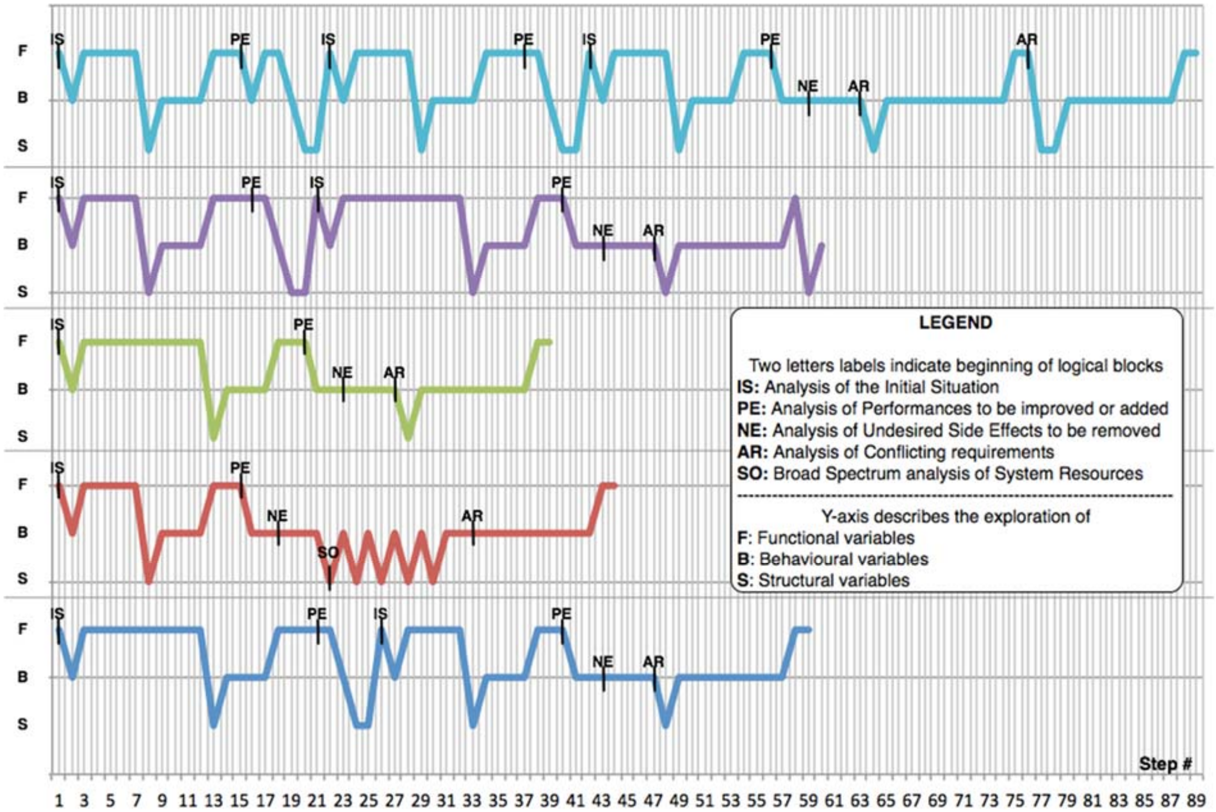

Figure 1. Five different examples highlighting similarities and differences between the behaviours of designers both in terms of Q&A sequence and of FBS level of description. Starting nodes of logical blocks of questions are characterized by two letters labels (e.g: IS, AR)

4.2 Evidences from the analysis of single design steps

Going into the details of each protocol, it is also possible to make comparisons between good results and bad results (in terms of problem representations); several examples are presented at different level of description in Table 3.

Three examples of questions are presented in Table 3, so as to ease the understanding about the ways the proposed approach provides useful elements of knowledge for the analysis of protocols:

- the first column distinguishes between the levels of description of the FBS ontology;
- the second column presents examples of questions as posed by the dialogue-based system;
- the third column collects answers from different users;
- the fourth column exemplarily assesses the correctness of the provided answers.

The words in square brackets reported in the second column are variables assigned by the user during previous HCIs; besides, the third column presents two different kinds of answers, i.e. discursive variables assigned by key typing and decisions (Yes/No) made by simple mouse clicking.

The detailed analysis allows to focus on specific behaviours of the designers, determining if and where they encounter difficulties in the analysis of the problems. According to these considerations, the combined examination of the thinking sequence and of the correctness of the answer allows to identify recurring critical situations and, thus, breakpoints causing the failure of analysis and compromising the entire design process.

With reference to the time required to carry out the complete analysis, it has been revealed that the Computer-Aided tool speeds up the analysis of protocols in design. The ratio between the duration of a design activity and its analysis is reduced to 1:1 or less.

Table 3. Examples of classification of questions according to the FBS ontology and answers provided by designers, with correctness assessment

Level of description	Text of the question	Answer	Correctness
Function	Which technical function is carried out by the [frying pan] in order to [cook food]?	Heat the food	Correct
		Easily clean the main body	Incorrect
Behaviour	Does the [dowel] provide any useful effects?	Yes	Correct
		No	Incorrect
Structure	Mostly focusing on those needed to [heat the food], list the relevant elements/components belonging to the [frying pan]. Type one component per row, using nouns without the article (i.e. screw, mouse, button...)	Main body, ring nut, pan handle, dowel	Correct
		Dowel	Incorrect (not complete)

5. Discussion and conclusion

The investigation of cognitive processes represents a key objective in order to identify the best strategies to achieve the highest benefits within design activities. In such a context, lots of scientific publications demonstrate that the protocol analysis represents the most widespread and repeatable method for mapping the design discourse. Whatever the distinction about the approaches (e.g. think aloud vs. conversational protocols; concurrent vs. postponed), these tasks always require the analyst to invest a great amount of time for extracting useful elements of knowledge.

With a different perspective, the trend of involving computers for aiding the design activities shows a progressive evolution towards the integration of tools aimed at supporting also the early phase of the whole process, namely conceptual design. However, there are lacks in the field of Computer-Aided systems for analyzing protocols, as well as just minor investigations have been conducted to study the effect of machines within the scope of guiding the conceptual design task.

The authors show an initial attempt to extract information about protocols by using an existing dialogue-based Computer-Aided tool for problem setting, highlighting potential opportunities arising by assigning computers the execution of some portions of the analysis. They proposed to a group of 22 people, with different level of experience in design, to analyze a real, despite simple, industrial problem using a Computer-Aided tool. The experiment represents an exploratory study, since further tests are required for a final assessment of the computerized procedure for Protocol Analysis.

Such system is not tailored to carry out the supply of protocols, and supports the analysis of technical problems rather than the whole conceptual design phase. Additionally, it intrinsically presents a quite rigid dialogue-based structure for driving the reflections of the designer. Despite such limitations, several evidences clearly emerged from the analysis of protocols using the FBS ontology as a coding scheme.

The adoption of such a Computer-Aided tool speeds up the Protocol Analysis task shortening the time in terms of a factor that ranges from 10 to 1000, according to the references available in literature. Indeed, the examination of the protocol of a person carrying out a problem analysis, has a duration less than or equal to the design activity, since the computer can actually deliver many of the time-consuming routine activities that are currently still in charge of the analyst. Moreover, a valuable contribution stands in the capability to increase the quantity of the people that can take part to this kind of researches, since most of the scientific references refer to experiments involving not more than 15 people. The in-depth examinations of the design mistakes emerging within each protocol can show which are the most critical cognitive steps that may prelude to breakpoints compromising the success of properly structuring the problem space. These evidences support the analyst in prioritizing interventions for preventing such situations and strengthening design methods. At last, also

considering the current diffusion of computers, this kind of approach dramatically reduces the need of using instruments and devices for recording and managing the entire activity.
The promising results obtained with this first attempt allow to hypothesize several directions for the prosecution of this kind of research. New tests with people using the Computer-Aided system for problem analysis on different problems may help in the identification of similarities, regularities as well as differences just by comparing the protocols and the followed threads of design thinking. Furthermore, critical design steps can be identified more easily throughout the introduction of the possibility of measuring the time elapsed to carry out each stage of the reasoning. The capabilities of the computer tool used in the experiment together with a module to record the duration of each design activity represent a preliminary list of requirements for the creation of tailored CAD software aimed at carrying out Protocol Analyses.
The enhanced time efficiency, previously assessed, can allow to widen the range of any experiments by increasing the number of involved designers. Such advantage can be exploited to overcome the limitations concerning the intrinsic rigidity of reasoning due to the adoption of a predefined sequence of dialogue-based HCI within the Computer-Aided system. To the purpose, comparisons could result useful between multiple protocols, obtained by the same sample of individuals with algorithms grounded on radically different design discourses (e.g. divergent vs. convergent, abstract vs. concrete, general vs. detailed). The plurality of experiments allows to release from a specific approach and to perform insightful investigations at the same extent of the traditional protocols, whereas the designer freely tackles a problem just by using “pen and paper”. At last, it is reasonable that, after the execution of different experimental activities with Computer-Aided tools for supporting protocol analysis, the initial list of requirements here proposed can be updated, according to the evidences emerged from the results. Additionally, a great amount of tests can shed light on the actual influence played by computers along the conceptual design and with reference to the stimulation of creativity.

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