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SPECIFYING AN INCLUSIVE MODEL OF PRODUCT-USER INTERACTION

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ABSTRACT
In order to design more usable and accessible products and services, designers require quick techniques to better understand how people interpret and use different interface features. A triangulated study was conducted, including a literature review, an evaluation of existing models of product-user interaction and observations with twenty users of washing machines. The study investigated the formation of users' cognitive representations of products and searched for a simple and effective method for modelling product-user interaction. In particular, the study found that the appropriate representation of product-user interaction should consist of two elements: (1) information on the functional parts of products and how they work (declarative element) and (2) information on users' goals and actions (procedural element). The conceptual graph analysis (CGA) was identified as the most effective model for designers as it captures both elements of product-user interaction in one representation and it does so in a clear and simple manner. Further research will continue to evaluate other models similar in nature to the CGA model in order to find an inclusive model of product-user interaction.

Keywords: Inclusive design, mental models, product-user interaction, conceptual graph analysis

1 INTRODUCTION
Products and services often exclude users through lack of accessibility and usability [1]. Inclusive design is a user-centred design approach that stresses the importance of understanding users' capabilities and creating products that address the needs and expectations of the widest design population, irrespective of age or ability [2]. Inclusive design embraces the principles of universal design, which is a design movement particularly popular in the United States and Japan. However, it is widely accepted in the inclusive design literature that designing 'one product for all' is implausible because people of different ages, capabilities and social and cultural backgrounds prefer different products [3]. Research shows that inclusively designed products not only minimise the exclusion of less capable users, but they are also easier for everyone else to use [4, 5]. There are also financial and legislative incentives for including older and disabled people in product design as both groups represent a considerable spending power [6] and a growing amount of legislation defends the rights of those disadvantaged users [7, 8].
To design more accessible and usable products, designers need to understand the interaction between product interface features and the diversity of user sensory, cognitive and motor capabilities [9]. However, designers are often restricted by, among other things, time and cost constraints and as a result they do not include heterogeneous users and their goals in designs, or involve them "too little" or "too late" [10].

1.1 Guidance
Research shows that many designers have little understanding of the fundamental factors of product-user interaction and users' internal representations of products, and there is currently no quick-to-use and understandable guidance that would raise designers' awareness in that regard [11]. The new guidance needs to go beyond the standardised checklists and textual guidelines and be represented in a visual form [12]. Thus, in order to raise designers' awareness on how users interpret and use different product features and, as a result, contribute to the design of more inclusive products and services, designers need to be provided with a usable and useful representation that captures the key factors of product-user interaction. This paper, therefore, addresses the importance of having a visual and

informational model which captures users' goals and actions as well as functional parts of the product in one representation. In search for such a representation, five pre-selected models have been evaluated in this paper for their effectiveness in capturing: (1) information on the functional parts of products and how they work and (2) sequences of actions that will lead users to accomplishing their goals with products. However, before the results of the evaluation on the usability and usefulness of these five models are discussed, it is first necessary to refer to the wide and varied literature on mental models in order to investigate how people construct internal representations of products.

2 MENTAL MODELS

Norman [13] believes that there are three cognitive models of every product:

1. the conceptual model, which involves the designer conceptualising the product;
2. the user's model, which the user develops to explain the operation of the product; and
3. the system image, which includes the appearance and operation of the product.

Furthermore, Norman [14] claims that an accessible and easy-to-use product can be designed by a means of matching the designer's conceptual model with the user's mental model through the use of the system image. This paper focuses primarily on the user's model, however, consideration is also given to the system image as it is a critical component through which a user develops an appropriate mental model of a product [15].

2.1 Definition of Mental Models

The theory of mental models was first formulated by Craik [16] who postulated that people represent the world they interact with through mental models. Johnson-Laird [17] agreed with Craik's [16] assumptions and further developed the theory of mental models by stating that people construct a working model of every object in environment in order to understand it. Extending the work of Craik [16] and Johnson-Laird [17], Krippendorff [18] adds that every user constructs a mental model about interaction with any product and the structural relationships between its components.

There are many definitions of a mental model; however, the information processing definition provided by Norman [19] has been found as the most suitable for the objectives of this paper. Explicitly, Norman [19] states that "the purpose of a mental model is to allow the person to understand and to anticipate the behaviour of a physical system. This means that the model must have predictive power, either by applying rules of inference or by procedural derivation (in whatever manner these properties may be realised in a person); in other words, it should be possible for people to "run" their models mentally".

Freudenthal [20] believes that appropriately represented users' mental models can be used by designers to derive appropriate design properties that would contribute to the design of more usable and accessible products.

2.2 Role of Memory

Mental models are created in short term memory (working memory) by a means of combining information from long term memory and information extracted from characteristics of a given task [21, 22]. It is noteworthy that people learn how to use new products by making use of their prior experience with other products [15, 23], and usable products can be based on previous, well-known and well-learnt designs [24]. Mental models are believed to be very difficult to infer as they can be incomplete, limited, unstable, unscientific and parsimonious and vary in complexity depending on the degree of previous experience [19]. It is believed that designers need to understand the way in which people construct and use mental models of products in order to design more inclusive product features [25].

2.3 Declarative and Procedural Knowledge

Based on the work carried out on structural and functional mental models in the early 1980's [26], Persad et al. [4] suggest that people's internal representations of products are composed of declarative and procedural knowledge. Declarative knowledge can be characterised as 'knowing that' and it contains information about what the functional components of a given product are and how they work. Procedural knowledge can be characterised as 'knowing how' and it focuses on information about actions that must be performed sequentially by a user to accomplish a particular goal [27]. Furthermore, it is argued that declarative knowledge describes objects and events by specifying the properties which characterise them, but does not pay attention to the actions needed to obtain a result, only on their properties. Whereas, procedural knowledge is instruction-oriented and is related to the procedure to carry an action out and focuses entirely on how to obtain a result [28]. Accordingly, Persad et al. [4, 22] state that a good representation of users' interaction with products should include: (1) information on different product features and how they work (declarative knowledge) and (2) information on the sequences of action between an initial state and the goal state (procedural knowledge). Therefore, since the adjectives 'declarative' and 'procedural' are very well suited for describing the types of knowledge that are required in modelling users' interaction with products, throughout this paper we will argue that an effective representation of product-user interaction should be comprised of the declarative and procedural elements.

Persad et al. [4] propose the use of a state-action diagram for representing information about users' goals and actions. An example of the state-action diagram illustrating the procedural sequence of use for a washing machine is shown in Figure 1.

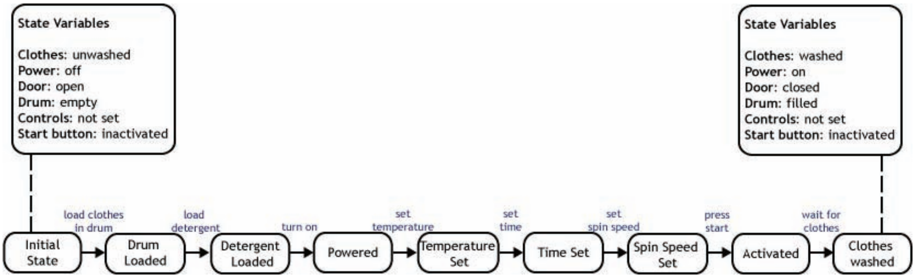

Figure 1: State-action diagram illustrating the procedural sequence of use for a washing machine.

Furthermore, there have been numerous representations devised throughout the 1980s that were primarily aimed at modelling the declarative knowledge of designers, i.e. the functional structure of a given product and the underlying relationships between all product parts. Examples of such models include functional flow diagram, structured analysis and design technique, N2 chart and input-process-output model, etc. [29]. However, despite the presence of all these highly-regarded models and the proposition of a methodology called task analysis for error identification (TAFEI), which incorporates such techniques as hierarchical task analysis, state-space diagram and transition matrix [30]; there is a significant lack of one unified representation that would include both the declarative and procedural knowledge of designers and users. Therefore, in search for one representation that would incorporate both elements of product-user interaction, we evaluated the representational capability and usefulness of five pre-selected existing modelling methods using the information gathered during twenty user trials. The user trials were conducted in order to elicit information on users' internal representations of two front-load washing machines of which one had a dial-based interface and the other one had a linear sequential interface. The information collected during the study was then represented using five models, which are discussed in section 4.

3 METHODOLOGY

It was necessary that the methodology for the user trials allowed users to express their intentions and opinions on the interaction with two front load washing machines and the ease of use and accessibility of these products. Two washing machines were chosen for the user trials because both of them were featured with complex interface design and they also differed with regards to the type of their control features and layouts. Since the focal objective of the user trials was to gain some insight into users' internal understanding of washing machines and what type of interface layouts they were more likely to learn fast and operate well, it was decided that one of the washing machines would have a dial-based interface and the other one would have a linear sequential interface. The dial-based interface consisted of features such as buttons, rotational dials and analog indicators, whereas, the linear sequential interface was comprised of such features as buttons, light indicators and a digital display. In addition, the dial-based interface had washing instructions printed on the external surface of the detergent drawer, while the linear sequential interface had a legend printed around the buttons. The images of the interfaces of both washing machines are illustrated in Figures 2 and 3 below.

Figure 2: A dial-based representation of a washing machine's control panel.

Figure 3: A linear sequential representation of a washing machine's control panel.

Given that only protocol analysis, which combines observation with verbalisation, is able to capture requirements from the working memory [31], it was decided that users' internal representations of two types of washing machines would be elicited by the use of the concurrent protocol (also known as think-aloud), which is a well-established methodology in the area of human-computer interaction [32]. In essence, the concurrent protocol requires a study participant to say aloud everything that enters their mind during the course of the experimental session, without making any attempt to modulate their utterances. The spoken data – the protocol – will then reflect the cognitive activity of the study participant [33]. The running commentary provided by the user is assumed to be unbiased as it consists solely of the user's perceptions. In addition, concurrent protocol allows the contents of short term memory to be expressed. Thus, all user observations can be recorded as and when they are made. The study participants were able to ask for clarification of the study's aims when any uncertainties arose and the researcher was able to ask questions when the participants' answers were confusing and unclear or difficult to interpret. Like any other research method, the use of the concurrent protocol had also its disadvantages. The main limitation of the concurrent protocol was that not all information or feelings were reported by the study participants during the user trials. To solve this issue, all user trials were carefully observed by the researcher in real-time and also recorded on a video camera in order to subsequently compare what the participants were actually doing with the product interface while verbalising their thoughts and actions and also during their silence breaks.

3.1 Procedure

Twenty user trials were conducted in order to elicit information on users' internal representations of two washing machines, the number and type of goals and actions they had whilst operating these products, and any cognitive and physical difficulties they encountered. Prior to the user trials, all participants were asked to sign a consent form that complied with ethical guidelines and given a brief description of the project as well as a sheet with written instructions explaining what the study required them to do. In addition, all participants were asked to describe the level of their experience in using washing machines. Although the sample was relatively small, the study provided some valuable data on the interaction between the functional structure of washing machines and the participants' intentions and understanding of it.

Participants, who were regular users of washing machines, were asked to set a wash of laundry and verbalise all the goals they had and the actions they were taking on the interfaces of both washing machines. Ten participants were asked to use a washing machine with a dial-based interface and the other ten participants were asked to use a washing machine with a linear sequential interface. In addition, all users were asked to describe any cognitive and/or physical difficulties they were having with setting up the wash. All user trials were recorded using a video camera with the consent of the study participants. Table 1 provides a clear description of the experimental setting.

Table 1: Description of the experimental setting.

Number of Participants	Capability	Method	Product	Aim
20 participants including: - 12 females (34-85 years old) - 8 males (27-89 years old)	Participants had different ranges of cognitive and physical abilities	Concurrent protocol	2 washing machines (WMs) including: - WM with a dial-based interface - WM with a linear sequential interface	1. to elicit users' internal understanding of the operation and use of two washing machines 2. to investigate the difference between the number of goals, actions and errors that users of dial-based and linear sequential interfaces had

3.2 Sample

The study participants were recruited through personal connections and health trusts in Cambridge, UK. Out of twenty participants, twelve were female aged between 34 and 85 years old, and eight were male aged between 27 and 89 years old. The participants had different levels of education and varying ranges of cognitive and physical capabilities.

3.3 Results of User Trials

In general, not all participants easily followed the spatial orientation of their washing machines' controls, which were either dial-based or linear. Approximately 40% of participants have also experienced problems with making a quick link between controls and their corresponding functional symbols. Furthermore, about 60% of users located a desired feature relatively quickly and their attention was being directed in one place at any one time resulting in not a lot of strain being put on their working memory. The difficulty encountered by nearly all users was with the understanding of the functionality behind the spin speed option. The user trials also provided some useful insights into the main problems that people encounter when using washing machines. Some of the problems mentioned in the study included: problems with bending down in order to load or unload a front load washing machine; too much strain being put on fingers when using a rotational dial on the washing machine control panel; not understanding what certain symbols displayed on the control panel meant; and difficulty understanding what spin speed option meant, etc. In general, the users' actions were very similar suggesting that the design of a washing machine requires a sequential operation and users need to perform their actions in a certain order to activate the washing cycle.

The number of users' goals and actions was counted by a means of analysing the video-taped user trials and assigning a number to each goal and action that every user verbalised and performed. In essence, the users of a linear sequential interface had a greater number of features to consider and use than users of a dial-based interface because the linear sequential interface did not have any programme options clustered together on one feature as was the case of a dial-based interface. The comparison between the number of goals and actions that the users of dial-based and linear sequential interfaces had is provided in section 6. In addition, two examples of representations that include sequences of goals and actions applied during the use of both washing machines are represented in the form of the CGA model in section 5.

4 MODELLING METHODS

After the elicitation of users' internal understanding of products, five modelling methods were examined in order to determine which one among these representations was the most effective at visualising the declarative and procedural knowledge of users. These five models were selected from a wide range of models found in literature and evaluated for being the most flexible and useful at representing functional structure of products and users' goals and actions. The five chosen modelling methods include:

- State Transition Diagram (STD);
- Statechart;
- Object-Oriented Analysis (OOA);
- Thimbleby-type State Diagram; and
- Conceptual Graph Analysis (CGA).

The results of this review are described in the subsequent sections and the results of the comparison between these five models with regards to capturing declarative and procedural knowledge of users are shown in Table 2. It needs noting that during the review it was assumed that although most of the evaluated models could capture users' goals, actions and products' functional parts, it was found that some of the models were better at representing and modelling the declarative and the procedural knowledge of users than others. For example, the OOA method was originally devised for modelling the functionality of a given product or system, however, if necessary, this method could be also 'stretched' by designers to model users' goals and actions but not always to a satisfactory standard. Nonetheless, the focal point of this review was to find one unified representation that, without being 'stretched' or adapted, would in its own right have the capacity to model the functional parts of products, as well as users' goals and actions.

4.1 State Transition Diagram

The state transition diagram (STD) is generally used for modelling the states of a given product, the conditions that cause a transition from one state to another, and the actions that result from the change of state [34]. During the review, the STD was found to be very effective at modelling the behaviour of the functional parts of products from both the designers and users' points of view (declarative element). However, this model can quickly become very tangled when all the functional parts of a given product are mapped on it and, as a result, it can be viewed as useless to designers who are looking for a simple and clear technique to support their designs. In addition, this model can be very useful at modelling the sequences of actions that a user needs to take to accomplish their goal with a product. However, the STD appears not to be flexible enough to model users' goals and, therefore, this model may not be a good support for designers of products for heterogeneous users for whom the understanding of what drives users during the interaction with products is the key.

4.2 Statechart

The statechart was devised by Harel [35] and it describes the behaviour of a given product through the hierarchy of diagrams and states, though, it does not provide a detailed description of the actions that occur. Additionally, the statechart can model parallel transitions that are independent of each other, as well as a product that can be in two or more states concurrently [29]. The analysis of the statechart on the example of a washing machine showed that, similarly to the STD, the statechart is more suited for modelling the functional behaviour of products (declarative element) and the sequences of actions rather than users' goals. In particular, the structure of this model does not allow for coherent display of how users' goals affect the sequences of actions taken on the product interface.

4.3 Object-Oriented Analysis

The OOA method organises a product as a collection of discrete objects that incorporate data structure and behaviour, and events that trigger operations and change the state of objects [36]. The OOA model is organised around data and allows for data within one object to be used by other objects [29]. The review has shown that the OOA representation is the most suitable for capturing the functional parts of products and how they work (declarative element). Furthermore, this model is organised around data rather than actions and, therefore, it does not provide good enough basis for modelling and matching the sequences of actions that a user needs to take to accomplish their goal with the functional parts of products. In addition, the OOA method is very weak at modelling how users' goals influence the operation of the functional parts of a given product.

4.4 Thimbleby-Type State Diagram

In contrast with Harel [35] and Yourdon [34], Thimbleby [37] proposes a new use for state diagrams. In particular, he suggests, and the review also confirms, that state diagrams can be used not only for describing the behaviour of the functional parts of products (declarative element), but also for describing users' actions. In addition, Persad et al. [9], having conducted an analysis of a toaster using the Thimbleby-type state diagram, argue that this type of state diagram is also very useful at evaluating the user feedback on each state of the product. However, this model in its present form is not suitable for modelling the goals that the users have before taking any action on the product interface and, therefore, it would not provide designers with a lot of support during the creation of inclusive products. Although the main disadvantage of this model is that it clearly does not have the capacity to capture users' goals and provide pointers as to how these goals structure the action-taking activity of users, it needs to be noted that during the evaluation this model was found to be very quick-to-use and understandable, and rather novel in the way it adds the user input to the functional design of products.

4.5 Conceptual Graph Analysis

The CGA representation is commonly used for developing a detailed system model, a database for expert systems and decision support systems, and functional models of systems [38]. Conceptual graphs contain information in the form of a concept or a statement that falls into one of five categories, including: state, event, style, goal or goal/action. The CGA model provides a well-organised framework for developing not only a detailed model of a product from the technical perspective, but it can also model the goals that users have and the different 'trial-and-error' actions that if appropriate may move users closer towards achieving their goals or if inappropriate may move users away from accomplishing their goals. This model also has the capacity to show more relationships between different parts of a product and in a more structured, descriptive and easy-to-follow manner than any of the other four models. In comparison with the aforementioned representations, it was found that the CGA model not only has the capacity to capture the functional parts of the product (declarative element), but it also models users' goals and actions (procedural element) on one representation, and it does so in a rather organised, untangled and quick-to-use manner. The model's notations are clearly stated and the designers can arrange the flow of information in any way that suits them and use colour-coding for visually separating the different notations of goals, actions and functional parts from one another (see Table 2).

Table 2. A comparison between different models with regards to capturing declarative and procedural elements of users' interaction with products.

Type of Representation	Declarative Element	Procedural Element
State Transition Diagram	✔ (functional parts)	✘ (goals) ✔ (actions)
Statechart	✔ (functional parts)	✘ (goals) ✔ (actions)
Object-Oriented Analysis	✔ (functional parts)	✘ (goals) ✘ (actions)
Thimbleby-Type State Diagram	✔ (functional parts)	✘ (goals) ✔ (actions)
Conceptual Graph Analysis	✔ (functional parts)	✔ (goals) ✔ (actions)

5 CONCEPTUAL GRAPH ANALYSIS

In order to illustrate the effectiveness and usefulness of the CGA model, ten representations of a dial-based washing machine and ten representations of a linear sequential washing machine were drawn using the information on users' internal representations of washing machines collected during twenty user trials. All twenty models were used during the analysis of users' goals and actions. The examples of two such models are shown in Figures 4 and 5 below.

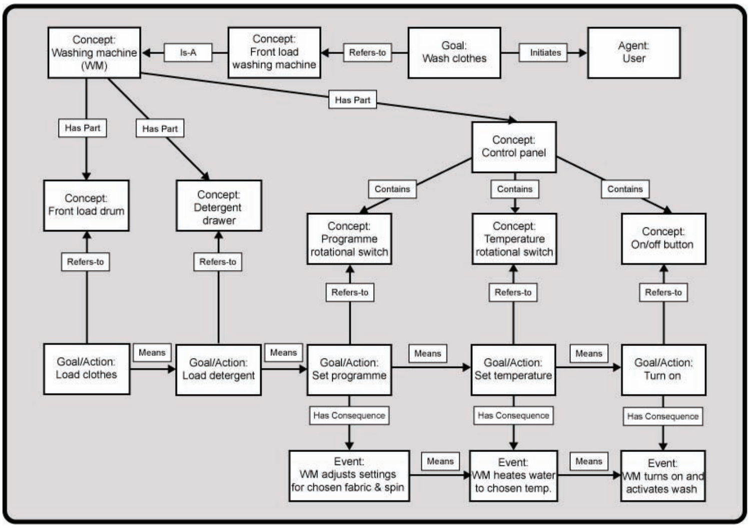

Figure 4: A conceptual graph analysis of a washing machine with a dial-based interface.

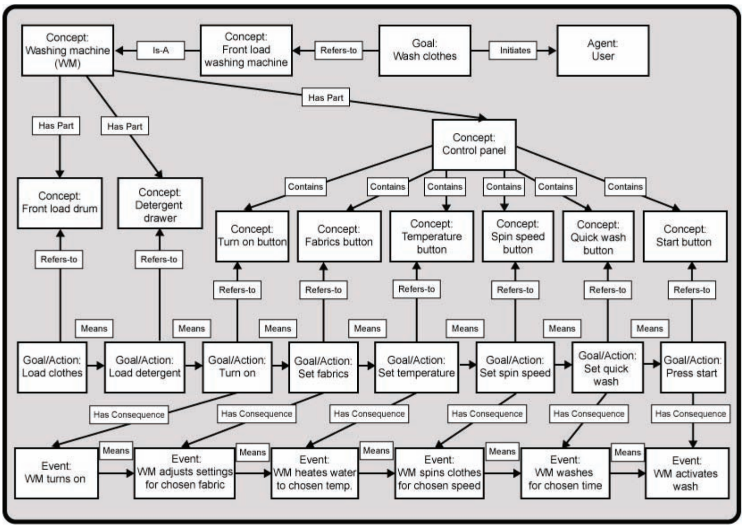

Figure 5: A conceptual graph analysis of a washing machine with a linear sequential interface.

The visualisation of participants' goals and actions as well as functional parts of two washing machines by the use of the CGA model indicates that people's goals and the ways in which they interpret and use different features on product interfaces vary quite substantially. Therefore, designers should embrace users' diversity by using supportive tools, such as the CGA model or others, in order to enable them to match their conceptual models of products with the understanding of users.

6 HEURISTIC PRINCIPLES

Tversky and Kahneman [39] suggest that people rely on heuristic principles in order to break complex operations into simpler and more manageable ones. In addition, Perkins [40] notes the use of heuristics as 'rules of thumb' that often help to solve certain problems but do not guarantee to lead to a required or desired outcome. Therefore, in order to identify the rules and the individual operations that users of washing machines have to consider and subsequently perform, a list of heuristic principles of a generic washing machine was developed. It was assumed that this list would be invaluable during the analysis

of the goals and actions that were mentioned by the participants during the user trials. A generic list of heuristic principles was compiled by a means of conducting a thorough analysis by the researchers of instruction manuals published by ten different washing machine manufactures and selecting the common activities that have to be performed on dial-based and linear sequential control panels and then breaking them into individual steps. During the compilation of the heuristics, it was assumed that the number of actions that needed to be taken on the washing machine interface would equal the number of goals. This list is as follows: (1) to plug a washing machine into the power supply; (2) to turn it on; (3) to open drum door (if the door is closed); (4) to load clothes into the drum; (5) to close drum door; (6) to open detergent drawer; (7) to find location for different types of detergent; (8) to add detergent (washing powder, softener, etc.) into the drawer; (9) to close detergent drawer; (10) to find fabrics control; (11) to set fabrics control; (12) to find temperature control; (13) to set temperature control; (14) to find spin speed control; (15) to set spin speed control; (16) to find programme control; (17) to set programme control; (18) to find start control; (19) to activate start control.
This list of heuristics shows that on average a generic user of a washing machine should have 19 goals and actions to consider and perform. Table 3 compares the number of the heuristic principles with the number of goals and actions mentioned by twenty study participants. The table also shows a difference between the number of goals and actions applied by the users of dial-based and linear sequential interfaces. It needs emphasising that the number of goals and actions was calculated by a means of analysing the video-taped user trials and assigning a number to each goal and action that every user verbalised and performed. Independent group t-tests were carried out between the "Dial" and "Linear Sequential" groups for the numbers of observed goals, actions and errors.

Table 3: The comparison of goals and actions during the usage of dial-based and linear interfaces.

Participants	Interface Type	Number of Goals	Number of Actions	Errors
Generic	Dial and Linear Seq.	19	19	0
1	Dial	6	8	2
2	Dial	5	6	1
3	Dial	6	8	2
4	Dial	6	9	3
5	Dial	5	6	1
6	Dial	5	5	0
7	Dial	6	8	2
8	Dial	5	8	3
9	Dial	5	5	0
10	Dial	6	8	2
11	Linear Sequential	8	8	0
12	Linear Sequential	8	9	1
13	Linear Sequential	9	9	0
14	Linear Sequential	9	9	0
15	Linear Sequential	10	11	1
16	Linear Sequential	8	8	0
17	Linear Sequential	8	8	0
18	Linear Sequential	9	11	2
19	Linear Sequential	10	10	0
20	Linear Sequential	9	9	0

As it can be seen in Table 3, the number of heuristics of a generic washing machine is approximately twice as large as the number of goals and actions of users of a linear sequential interface and four times greater than the number of goals and actions of users of a dial-based interface. This could be attributed to the fact that the study participants did not tend to verbalise such goals and actions as, for example, 'to open/close drum door' or 'to find fabrics control' and, therefore, these actions and goals were not included in the overall count.

Moreover, Table 3 shows that the number of goals and actions of users of a dial-based interface were significantly lower than the number of goals and actions of users of a linear sequential interface. There were significantly less goals for the dial-based interface (Mean = 5.5, df = 18, $p < 0.01$) than the linear sequential interface (Mean = 8.8) and significantly fewer actions for the dial-based interface (Mean = 7.1, df = 18, $p < 0.01$) than the linear sequential interface (Mean = 9.2).

This may be because the participants had a tendency of basing the number of their goals and actions on the number of the interface features. For example, a washing machine with a linear sequential interface had a greater number of features to consider than a dial-based interface because it did not have any programme options clustered together on one interface feature as was in the case of a dial-based interface. Therefore, a user operating a linear sequential interface had a greater number of goals and actions to consider. The small but significant increase in the number of errors in the dial interface (Mean = 1.6. df = 18, $p < 0.05$) compared to the linear sequential interface (Mean = 0.4), suggests that, on the same basis, the linear sequential interface layout allowed for fewer alternative actions at each step and, therefore, permitted less opportunities for erroneous action.

7 DISCUSSION

The analysis of the representations elicited during the user trials consistently shows that initially people have the same 'master' goal to wash clothes or other fabrics when they use a washing machine. All representations also indicate that all study participants had three further common goals, namely: to load clothes into the drum; to load detergent into the detergent drawer; and to turn the washing machine on. However, the participants' responses varied when it came to setting fabrics option, temperature option, spin speed option and programme option, as well as activating the wash. Participants who operated the dial-based interface had certain functions clustered on one dial setting, and as a result, they had fewer goals to consider and actions to perform. Although, initially easier to understand, the linear sequential interface required users to consider a higher number of goals and perform more actions. Another important finding of the user trials was that the linear sequential interface, usually featured with push buttons, was generally easier to use by the participants with lower dexterity capabilities than the dial-based interface. In addition, as the column with errors in Table 3 indicates, users operating a washing machine with a linear sequential interface made fewer errors than users operating a washing machine with a dial-based interface. Overall, it was found that the washing machine with a linear sequential interface had more accessible and usable control features. This may be significant for users experiencing decline in cognitive and physical capabilities.

Another interesting observation made during the user trials was that the layout of the dial-based interface (see Figure 2) required users to rely more on their declarative knowledge as they had to think about how the product works due to different types of functionality being clustered on one dial and symbolic annotations. Whereas, the washing machine with a linear sequential interface required users to rely more on their procedural knowledge (see Figure 3) as each functional feature on this product was labeled separately and arranged in a sequential form that matched users' goals and actions.

Out of the five models reviewed in this paper—all highly-regarded by the design community—the CGA is the only representation that in a unified manner captures the two fundamental elements of product-user interaction, explicitly: (1) information on the functional parts of products and how they work (declarative element) and (2) information on the sequences of actions that will lead users to accomplishing their goals with products (procedural element). The analysis and use of the CGA model and its comparison with the other four models has also shown that conceptual graphs can provide a quick, understandable and structured support to designers that want to know more about the end users' cognitive and functional capabilities and understanding of products. In addition, the structure of the CGA model allows for its notations to be clearly stated and the designers can arrange the flow of information in any way that suits them and use colour-coding for visually separating the different notations of goals, actions and functional parts from one another (see Table 2).

8 CONCLUSIONS AND FUTURE WORK

In this paper, the results of literature review on users' internal representations of products were presented, five methods for modelling product-user interaction were discussed and trials with everyday users of two washing machines were described. The user observations were aimed at eliciting users' internal understanding on the use and operation of two washing machines. The findings from the user trials indicate that a washing machine with a linear sequential interface had more features to operate and consequently required users to have a larger number of goals and actions to consider and perform than a washing machine with a dial-based interface. Despite this, the study has found that users of a linear sequential interface made fewer errors than users of a dial-based interface and the control features on the linear sequential interface were said to be more accessible and usable by the participants with lower visual, cognitive and dexterity abilities. Furthermore, the information extracted from the observations with users was represented in the form of five models, which were then evaluated for their effectiveness in modelling product-user interaction. In particular, the study found that the appropriate representation of users' interaction with products should consist of two elements: (1) information on the functional components of products and how they work (declarative element) and (2) information on users' goals and actions (procedural element). The CGA model was found to be the most usable and useful representation at supporting designers in creating products for heterogeneous users. The main advantage of the CGA is that this model not only captures the functional parts of the product as well as users' goals and actions in one representation unlike any of the other four evaluated methods, but it also does so in a clear and simple manner, which is of great use to busy product designers. However, the CGA method is not without its limitations mainly because this model generally provides a less detailed description of the functional parts of products than, for example, the description provided by the OOA model. Therefore, further research will continue to evaluate other models similar in nature to the CGA model in order to find an inclusive model of product-user interaction that would be quicker to use and more descriptive than the CGA model and would support designers in designing for as many people as possible.

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