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THINKING AND RE-THINKING VERBAL PROTOCOL ANALYSIS IN DESIGN RESEARCH

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ABSTRACT
This paper assesses the appropriateness of verbal protocol analysis (VPA) as a means of analysing design activity. Design activity includes human cognitive abilities such as creativity, synthesis, and problem solving. These can vary depending on the design disciplines and design practices involved such as industrial design, engineering design, etc. In order to find out how these abilities are expressed, a study of VPA was carried out based on interviews with two researchers from different disciplines – product design and machine design – and their experiences were compared. The issues in this paper cover general reflections, positive aspects, negative aspects, evaluation (Meta-VPA), ethics and conclusions. On the basis of the results from the analysis of the interviews on VPA, it seems to be significant to carefully consider the reasons for mapping and analysing design activity and how the results may be put into practice.

Keywords: appropriateness, cognition, ethics, meta-VPA, methodology, verbal protocol analysis

1 INTRODUCTION
Verbal protocol analysis (VPA) is a method of bringing out into the open that somewhat mysterious cognitive ability of designers. Of all the empirical, observational research methods for the analysis of design activity, VPA is the one that has received the most attention in recent years [1]. Ericsson and Simon [2] are the original disseminators of the VPA method (see [3, 4]). The pros and cons, as well as the techniques for VPA, are described in depth in their work.
The basic strategy of VPA involves getting people who are doing something to verbalise their thoughts and feelings as they do whatever they are doing. It requires some "training" of participants to get them used to verbalising what usually are only internal dialogues with themselves [5]. VPA also maps how users describe themselves as interacting with objects. Both the verbalising and interaction are rooted in language and cannot be separated from the respondents' linguistic use of objects in communication with others [6].
This method differs from interviews in that the person does not reflect on what he/she is doing, but rather just says "what" he/she is doing. It is up to the coder to analyse the protocol and find the cognitive process behind the action (see [7]).
VPA is an analysis tool that has been used and recognised by many researchers including psychologists, scientists, architects, designers, and engineers in order to analyse design activity. Design activity encompasses some of the highest cognitive abilities of human beings. Every normal person is capable of exercising such abilities, but it is in design activity that they are most frequently stretched to their limits, and the most able designers clearly exercise some exceptional levels of ability. A varied range of research methods has been developed and adopted for the analysis of design activity. The range extends from philosophical reflection to empirical investigation, and includes study of both the natural and the artificial intelligence of design (see [1]).
According to Sim and Duffy [8] the apex of design activities is synthesis. Synthesis is considered here as a compound activity as it involves search, exploration and discovery of design solutions, and composition and integration of these solution. Figure 1, presents a taxonomy of design definition activities in which synthesising is the result of abstracting and generating design concept(s) and structuring concepts to form a whole. This figure is adapted from the graphical model of Andreasen [9] and Hasen and Andreasen [10] which has two axes labelled as abstract/concrete and undetailed/detailed.

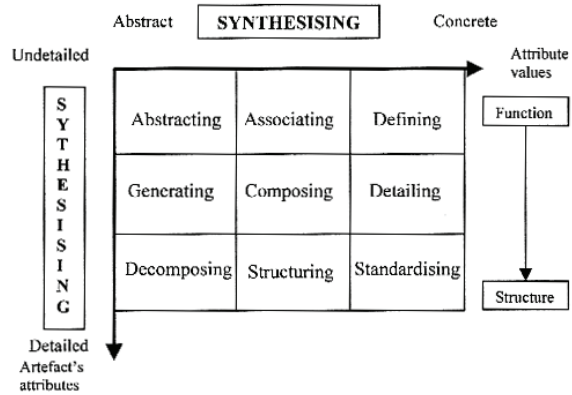

Figure 1. Taxonomy of design definition activities [10]

2 AIM OF VPA AND THE RELEVANCE TO THE COGNITIVE CHALLENGES

The VPA approach aims to elicit the inner thoughts or cognitive processes that illuminate what is going on in a person's head during the performance of a task, for example painting or solving a problem. The method for VPA proposed by Ericsson and Simon [2] is following:

- The participant's verbalisations are transcribed into a protocol and the problem solving process and protocol are analysed to extract the vocabulary of objects and relations needed to define the problem space and operators.
- The protocol is then segmented, each segment corresponding to a statement.
- The list of actions used to encode the segments can be extracted from the elicited vocabulary or from a pre-determined coding scheme.
- There can be several levels of analysis. The episodes and actions can be aggregated (which is often the case in design studies), for example.

In order to ensure reliability, the coding should be done by two coders independently.
For details regarding the VPA method, please see Ericsson and Simon [2], and Pressley and Afflerbach [11].
At the beginning of a VPA experiment, a small exercise with no link to the object of the experiment is presented in order to train the participant to "speak aloud." In teaching rounds at the hospitals, senior physicians perform a version of this when they speak aloud about how the act of diagnosis while medical students listen, presumably learning the experts' thinking processes by hearing them in action [5].
Wilson [12] used VPA in his doctoral dissertation where he investigated students' understanding and problem solving in college physics. Twenty students in individual 45-minute sessions were videotaped and asked to talk aloud as they tried to solve three introductory physics problems of moderate difficulty involving Newton's second law. This involved a concurrent rather than retrospective approach because students were engaged in thinking aloud and problem solving concurrently, as opposed to explaining their thinking and reasoning retrospectively after solving the problems. Wilson notes that concurrent designs are generally considered more reliable because the verbal data and protocols that are generated do not depend on subjects' short-term memory recall of the cognitive processes and strategies they think were engaged while solving problems. Wilson was able to pinpoint the cognitive challenges that confronted students as they tried to derive the acceleration of a particle moving in various directions and angles with respect to a particular reference frame [2].

3 PROCEDURE OF THIS PAPER

In this paper, we investigate if:
a) VPA is suitable for analysing design activity, and
b) How VPA can be adjusted to best meet the needs of design activity research.
When we initiated the study, we had varying experiences of VPA. In order to come to an understanding on the topic we decided that besides literature studies we would also gather information

through a couple of interviews. Despina Christoforidou and Andre Liem, who had experiences in organizing and moderating experiments and interviews, conducted two interviews. The first interview was with the first author, Shahriman Zainal Abidin, who was considering adopting the VPA method in his own future research. The second interviewed researcher, Damien Motte, had used VPA in his research. We thought it would be interesting to bring together theoretically and practically experienced VPA researchers who in addition came from different areas of design, such as product design, machine design and communication studies and compare their experiences.
The questions posed were:
What did you want to study/measure?
Why did you select VPA?
Was the outcome of your VPA satisfactory?
What was positive?
What was negative?
If you were to conduct a VPA session today, what would you do differently?
If you did not use VPA, what method would you choose instead and why?
The interviews are attached as appendix A and appendix B.

4 DISCUSSION

In this section, reflections will lead discussed based on the positive aspects and the negative aspects outcome from the interviews.

4.1 General reflections

VPA is a valuable method because it is based on direct evidence and takes into account the designer's way of working. But there has been little adaptation of VPA for the field of design research; the method has often been adopted as it is. The aim of VPA is to evaluate the design activities and their relationships.
The design evaluation activities in general are to reduce the complexity of the design solution space based on the ill-defined design problems. Through activities such as evaluating and decision making, infeasible or less optimal solutions are ruled out, hence leading to reduction in the search space of design solution. The design evaluation activities are related as shown in Figure 2.

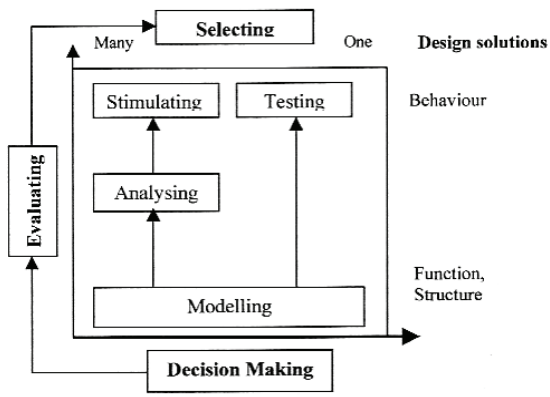

Figure 2. Design activities and their relationships [10]

Moreover, the VPA has been developed for well-defined problems and short tasks (resolution of an equation for example), and may not be adaptable for design problems [3].
In many experiments using VPA, the experimenter tries to move from hypotheses to a coding scheme. It is illustrated in the form of episode and action. The hypothesis to be tested, deals with the relation between information of the mental model in relation to the mental simulation code and uncertainty in real-world design. A mental model is a representation of some domain or situation that supports understanding, reasoning, and prediction (see example in Table 1).

Table 1. Example of a mental simulation [17]

Initial representation	Could you add something so that you couldn't close this thing because there would be something in the way when you try to fold it this way…
Run	But if this thing goes this way, then it is in a position to allow the ear to enter…But then I just don't know how it should be folded… cause if it is folded this way then it will come out here… then it should be folded unevenly somehow… You should fold it oblique.
Changed representation	It wouldn't make any difference one way or the other. It would fold the same way, and come out on this side the same way

To illustrate different kinds of codes, two different measures of information uncertainty have been used, one relaying on syntax, the other on a combination of verbal and visual information taken from a video (see example in Table 2).

Table 2. Examples of information uncertainty using syntax [17]

Utterance	Code
Cause I'm **not sure** whether you would fold it around the back.	Uncertain
I **think** so too, but before we get too cocky, let's make a model…	Uncertain
Well, I **guess** it's a combination of moisture and heat isn't it? I **suppose** it has to be.	Uncertain
It has to push from the start	Not uncertain
Yes, but the problem is that you can't hit it later…because it's too small	Not uncertain
It…then we have… then we lose the possibility of folding it back.	Not uncertain

Furthermore, for the categories of the coding scheme, the experimenter can categorise the coding based on the time concerning the segments (see Table 3).

Table 3. Categories of the Coding Scheme [13]

Category	Description
Irp	Concerns the time segments where the subject asks the experimenter for complementary information on the problem itself. That is, the subject asks for information helping in the understanding of the problem, not for directly developing a solution.
Sp	Concerns the time segments where the designer reformulates, re-frames the problem.
Ep	Concerns the time segments where the subject evaluates the problem itself.
Irm	Concerns the time segments where the subject asks the experimenter for complementary information on mechanics that concerns formulas and models…
Sm	Concerns the time segments where the subject describes the solution in mechanical terms (force, moment; strain, stress; buckling; etc.)
Em	Concerns the time segments where the subject evaluates his or her mechanical model.
Irs	Concerns the time segments where the subject asks the experimenter for information that directly helps the synthesis activity. It can be catalogues of components, of joints…
Ss	Concerns the time segments where the subject creates the form and layout of the support.
Es	Concerns the time segments where the subject evaluates his or her solution (layout, form, or the overall solution).
Ird	Concerns the time segments where the subject asks the experimenter for information that helps in dimensioning.

Sd	Concerns the time segments where the subject dimensions the artefact.
Ed	Concerns the time segments where the subject evaluates the results of dimensioning.
D	Concerns the time segments where the subject documents his or her work with a detail drawing.
Eego	Concerns the time segments where the subject evaluates him or herself.
O	Concerns the time segments where the subject organises his or her way of working.

The experimenter is also able to see the pattern of activities by using a frequency table as illustrated in Figure 3. This figure is based on the example of "Problem-solving activity of an expert," research using VPA as a method, carried out by Motte, Andersson, & Bjärnemo [13]. In this analysis, they referred to the work of Lonchampt, Prudhomme, & Brissaud [14], and Eder and Hubka [15] as a basis in order to conduct VPA experiments.

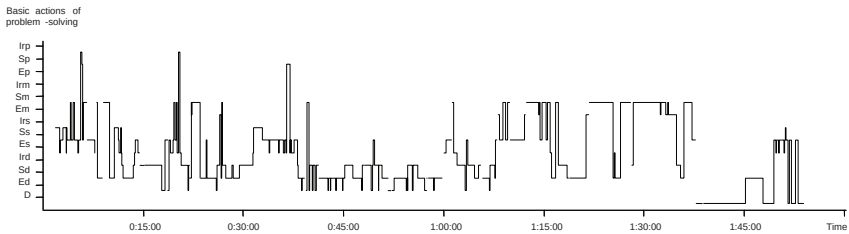

Figure 3. Problem-solving activity of an expert [13]

In the VPA experiment setup, four cameras were installed to capture different views such as: a general overview of the room, a closer view of the subject faces when sitting at the table, the white board, and overhead view of the drawing pad/table top (see Figure 4). Generally, the presence of the researcher in the setup while the experiment is ongoing in order to insure the participant's continuous verbalization is an obvious limitation of the VPA-method.

Figure 4. Verbal protocol analysis experiment setup

One could argue that this affects the VPA experiment and that the outcome would be different if the participant was alone and/or did not have to even verbalise. The researcher should literally become a fly on the wall in order to minimise the effects of his/her presence and at the same time be an eye

witness. This problem could perhaps be remedied by technical solutions for indirect observations, video recorders, usability laboratories, etc.
Other objections regarding VPA are raised by linguistic researchers. They argue that the necessity of verbalisation which VPA entails influences the design process. This means that the solutions produced during a VPA session differ from the solutions the designers would come to in real life [16].
A possible way around these problems is presented by Christensen [17]. He suggest an "in vivo" research methodology which means studying, for instance, design thinking live or online as it takes place in the real world. The method relies on the natural dialogue between designers.
We have summarised the positive and negative experiences stated by the researchers we interviewed.

4.2 Positive aspects

The positive aspects of VPA we found comparing the two interviews are the following:

- VPA as an instrument has been used and recognised by many researchers in order to analyse design activity. It is one type of empirical research which is based on direct evidence. And this direct evidence is recognised by many researchers who come from engineering, psychology, as well as social science.
- VPA is a method which takes into account the designer's way of working, thinking and partially the context in which design is performed. The use of VPA makes it possible to see, interview and design an activity move in parallel, and from that we can abstract the finding based on direct evidence by using our own knowledge and interpretation. However, for a more complete picture, there is a need to capture, not only verbal expression, but also the subject's gestures, attitudes, emotions and so forth in order to comprehend the full dimensions of the design thinking process.
- Coding scheme that brings together various approaches and addresses the problems can be identified in the designing process through patterns in the data coding and data analysis.
- VPA is based on qualitative inquiry. In terms of determining a number of subjects involved, there are no rules for sample size in qualitative inquiry. Sample size depends on what you want to know, the purpose of the inquiry, what's at stake, what will be useful, what will have credibility, and what can be done depending on available time and resources [18].
- It permits quantification of the (qualitative) results, which makes comparisons much easier.
- It is a suitable method for comparing outcomes between different levels of expertise [19, 20]. This enables testing the consistency of the verbal information in order to investigate the validity of verbal reporting in relation to the design thinking.
- The records can be used with any other text analysis method.

4.3 Negative aspects

All methods have their *Achilles' heel* and this is valid for VPA as well. Below we summarise the difficulties the interviewed researchers experienced with VPA:

- VPA is very time-consuming. This makes it difficult to perform enough experiments to get statistically valid results.
- The segmentation of the protocol into elementary episodes and the choice of suitable categories remain highly subjective, which makes any statistically valid results from VPA relative.
- The interpretations of the results derived from VPA are often speculations that cannot be proved.
- There are no guarantees that the VPA experiment has been conducted with no significant obstruction by the interference of the researcher.
- It is difficult to establish how the design activity is affected by being forced to verbalise simultaneously – i.e., a category with the selection of coding scheme. Too many categories of coding scheme in design can makes result too complex, potentially masking relationships and patterns in the data, and are generally difficult to understand.
- The data from the study can be questioned by researchers' who come from other disciplines where quantifying qualitative data is less important.
- Other less time-consuming methods such as interviews and/or observations may result in similar findings.

5 CONCLUSIONS

Our intention was to establish whether VPA is a suitable method to evaluate design activity. Like all methods it has its pros (positive) and cons (negative), which makes it difficult to claim that VPA is a good or bad method. It depends, of course, on the object of the study, the purposes and skills of the researchers, the validation of the outcome through additional methods.

In order to evaluate, it is essential to reach a level of profound understanding. As design research is a fairly new academic topic, the VPA method has not been used *by* design researchers, *for* design, *through* design for a long time. This leads to "borrowing" methods, etc., from other areas and it takes time to make proper adjustments. As we have already stated, the VPA method has been developed for well defined, linear problems and there has been little adaptation of VPA for the field of design research; the method has often been adopted as it is. The "in vivo" research methodology suggested by Christensen [17] could be a possible way of successfully adapting the method of VPA to suit the nature of design activities as the method relies on the natural dialogue between designers. *In vivo* studies are carried out within a natural setting. In contrast, the *in vitro* studies are conducted in a laboratory or a controlled experimental environment and thus allow the researcher to study expert thinking and reasoning "online" in the real-world. It may therefore prove to be very fruitful to combine aspects of the *in vivo* approach with VPA, especially in contexts where the technical content is low and the focus of the studies lies within the sphere of the humanities.

With the intention of evaluating the appropriateness of VPA for research in design, two comparisons would be interesting: 1) compare the VPA outcomes between the different design disciplines, and 2) compare and combine outcomes of traditional VPA with the *in vivo* approach or *in vitro* approach, and set up a VPA study on VPA, a kind of meta-VPA, in order to observe how researchers conduct research. This could provide valuable information and comparisons and lead to conclusions based on solid understanding regarding similarities and differences of how the VPA method is being used within various research fields.

The VPA method was initially developed by psychologists who wanted to understand the cognitive process. Today it is possible to combine VPA with a simultaneous brain scan to detect which parts of the brain are activated and when. Based on such methods it is possible, for instance, to argue whether genius is made or born [20]. Research outcomes on creativity could be applied to measure peoples' creativity which could be used in a discriminating manner.

We should question our intentions seriously every time we set out to measure something, what it is that we want to measure and why and make serious ethical considerations while designing methodological experiments. "Scientific proof" in the wrong hands might turn to ammunition for dangerous argumentation.

A strong methodological foundation is therefore of great importance, but what is absolutely imperative is to have the tools to judge a method's appropriateness for each case. The appropriateness of methods is directly connected to the context in which they are practiced and the audience to which they are directed [21]. This might serve as an explanation as to why VPA has become so popular in the discipline of engineering where it is common to quantify data.

Creativity is a fascinating talent and cognitive psychology researchers have tried, for instance, to analyse the constituent parts of creativity in order to understand, generate or even control its mechanisms in a more sufficient manner. Similarly, the design process is a creative process and is therefore surrounded by similar attention. To have designers verbalise while in the midst of the process provides researchers with the opportunity to gain insight into the mystique of "tacit knowledge."

There is a risk, though, that this could be an illusion because of the different degrees of subjectivity the VPA involves. In addition, there is a key question regarding the nature of the "tacit" factors and whether they should be demystified or not.

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APPENDIX A

Shahriman Zainal Abidin on Verbal Protocol Analysis

VPA: verbal protocol analysis

What did you want to study/measure?

I want to study the phenomena of design activity in the embodied mind in relation to thinking about form development in design. With VPA, it's allowing me to study on how designers think during the designing process.

Why did you select verbal protocol analysis?

I am interested to select VPA because it has been used and recognised by many researchers as a method and an instrument (equipment for measuring and recording data) in order to analyse design activity.

The method is based on the idea that thoughts are in principle formed by means of language. Therefore VPA method only makes use of spoken language information as data to learn about the content of thought. However, for a more complete picture, there is a need to capture not only verbal expression, but also the subject's gestures, attitudes, emotions and so forth in order to comprehend the full dimensions of the design thinking process.

Since this experiment is based on qualitative inquiry, in terms of determining the number of subject involves according to Michael Quinn Patton in his book "Qualitative research & Evaluation methods" there are no rules for sample size (number of subject) in qualitative inquiry. Sample size depends on what you want to know, the purpose of the inquiry, what's at stake, what will be useful, what will have credibility, and what can be done with available time and resources.

This method and instrument has been used by many researchers from the area of cognitive science, neurology in psychology, etc.

Was the outcome of your verbal protocol analysis satisfactory?

The result is expected to be satisfactory because it is one type of empirical research which is based on direct evidence. This direct evidence is recognised by many researchers who come from engineering, psychology, as well as social science.

Since, I am examining the activity of short-term memory; the outcome of the VPA is satisfactory. However, the follow-up interview is required if there is missing of additional information needed.

If I can compare with other career levels of designer like student, novice, intermediate, senior, and professional, I can test the consistency of the verbal information in order to investigate the validity of verbal reporting in relation to the design thinking. It is my contention that designing a way of thinking that incorporates many separate modes of thought in much the same way as talking is a way of thinking, like "design" thinking and "talking" thinking.

What in your opinion was positive?

I can use coding scheme that brings together various approaches and addresses the problems that I have identified in the designing process through patterns in the data coding and data analysis.
I can probably derive guidelines, theories and tools that would manage subjective thinking and give more objectivity to form decisions. This should result in a framework/model, or in the most ideal situation, a database to assist the designer to make form decisions or develop form variations at the detail level.

What was negative?
Issue here is on how to develop a coding scheme related to product design (industrial design) process. Can I use the same template from the engineering design which is more toward "problem solving" and "synthesis-analysis" approaches or shall I create a new one relates to the "intuition" approach in the design process.
Too many categories of coding scheme in design can make result too complex, potentially masking relationships and patterns in the data, and are generally difficult to understand.
There might be poor cooperation from the subject who comes from different levels of career development. Especially getting an expert involve in the observation part. The negative side is that the data from the study can still be questioned by researchers' who comes from other fields. So I need a strong foundation in order to use this method and instrument. Since I came from the design-based background, I need to develop my research focus more on design activities. The use of VPA is just as a method and an instrument for analysing design activity. I need more literature to support the argumentation.

If you were to conduct a verbal protocol analysis session today, what would you do differently?
If I were to conduct a VPA session today, I would make sure that the setup is based on the previous work. This is important in terms of the recognition of the experimentation. In addition, I would use other instruments like questionnaires and interviews in order to get additional answers. For me, mix method or multiple case studies are needed if we intend to get in-depth info.

If you did not use verbal protocol analysis, what method would you choose instead and why?
If I would not use VPA, I would use an interview. This is because we still can get the information from the interview. The use of VPA is to see interview and design activity move parallel, and from that we can abstract findings based on direct evidence by using our own knowledge and interpretation.

APPENDIX B

Damien Motte on Verbal Protocol Analysis
VPA: verbal protocol analysis
ED: embodiment design
DD: detail design

What did you want to study/measure?
The main research goal was to develop a methodology to help the mechanical engineering designer during the later phases of the design process. The later phases are called the embodiment and detail design phases, where the engineering designer gives a physical structure to the concept and also designs unique parts (or details). It was noticed that many methods in conceptual design were not as successful as thought, because they did not take into account the designer's way of working, thinking and the context in which design was performed. A deeper understanding of these phenomena was necessary. The study was thought to be two-folded:
1) study the reasoning/rationale of the designer
2) study the designer in context (in the field)
The study of the first point, which is our concern here, was meant to be mainly explorative in nature: almost nobody had made an in-depth analysis of the design activity in the later phases of the design process. So the questions were:
a) which design tasks are performed (e.g., criteria specifications, welding dimensioning...)?
b) which problem-solving tactics and strategies are applied?
c) what needs to be improved?

Experts and students were compared to each other.

Why did you select verbal protocol analysis?
It is the analysis tool that has been mostly used in our field for this kind of research project. With many categories developed by other researchers (for conceptual design), it was thought easy to re-use them for ED and DD and compare them to previous results. It also seemed to be the most accurate method for that purpose. Other methods, like interview, questionnaire, log-book, retrospective were more biased, as they either are reconstitutions (interview, questionnaire, retrospective) or the researcher has no control over it (log-book, questionnaire). Experiments were not possible at that point (what to experiment?). Other text-based analysis methods were unknown at the time.

Was the outcome of your verbal protocol analysis satisfactory?
It gave mitigated results:
It has permitted the quantification of the results, which makes comparisons much easier.
VPA basically gives only the following results:

- frequency of apparition of a category
- relations of precedence with other categories
- time to perform a category
- with the right amount of experiments, a pattern of design activity can be extracted and validated
- shows whether some categories are missing, whether the present categories mirror the actions performed.

But, it neither validates the categories, nor shows that some categories are "better" than others. This is an advantage and an inconvenient: I could observe the same experiments with general problem-solving categories (information search, problem identification, solution generation, evaluation) and design activities (e.g., dimensioning), but I cannot prove that these categories are relevant and to which degree.
I did not perform enough experiments to get statistically valid results. It is very time-consuming.
The segmentation of the protocol into elementary episodes and the choice of a suitable category remain highly subjective (which makes any statistically valid results from VPA relative).
Not all the results presented derive from VPA. The simple observation of the tape already gives important results.
The interpretations of the results derived from VPA are often speculations (not proved).
What was really positive is that it showed the limitations of the development of design methodologies for routine design: it showed, for example, that such methodology should be as non-intrusive as possible.
The records can be used with any other text analysis method.

What in your opinion was positive?
See above.

What was negative?
See above.

If you were to conduct a verbal protocol analysis session today, what would you do differently?
I would try to collaborate with a cognitive psychologist, who would help with the method, the coding scheme (categories) and the theories behind, and the interpretation of the results.

If you did not use verbal protocol analysis, what method would you choose instead and why?
See second question.