

PROTEUS: Artefact-driven Constructionist Assessment within Tablet PC-based Low-fidelity Prototyping

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Low-fidelity prototyping is a widely used HCI knowledge elicitation technique. However, empirical evaluation methods for low-fidelity prototyping have remained relatively static even with the development and use of software prototyping tools. In this paper, we describe a framework based on constructionism theory to model design artefacts as measurable constructs within low-fidelity prototypes. This provides a novel approach to acquiring further cognitive user metrics within software based low-fidelity prototyping in the HCI domain. We describe two mobile software tools, PROTEUS and PROTEUS EVALUATOR, developed for the Tablet PC platform, which use our framework to aid our understanding of prototypes during their temporal construction. Results of using the tools in two scenario experiments are reported, each conducted with 40 HCI postgraduate students.

Keywords: low-fidelity prototyping, constructionism, knowledge elicitation, Tablet PC software, HCI software tools.

1 Introduction

Knowledge elicitation methods in HCI are a critical function to the success of requirements and design gathering stages [Maiden et al. 1995], usability testing and user evaluation stages of software development [Zaphiris & Kurniawan 2001]. Examples of this start with initial questionnaire feedback, requirements task walkthroughs, interviews techniques, and focus group debates. It can rapidly scale

upwards to more complex psychometric and design and evaluation processes such as various fidelities of prototype construction, direct and indirect observation practices for monitoring user actions and response time comparisons, and methods for eliciting mental categorization models e.g. in distinguishing expert and non-expert technology usage patterns.

A wide variety of tested and proven experimental user-based techniques exist for practitioners [Burge 2001] to utilize. However, as HCI specialists will know from experience, knowledge acquisition and analysis of data from traditional user-based methods is time consuming and usually requires experts in their respective fields. As Kidd [1987] defined, knowledge acquisition of experts involves the following processes:

1. Deploying a technique to elicit data from the expert users.
2. Interpreting verbal data and infer the underlying knowledge and reasoning of the users.
3. Utilising this interpretation to construct a model or language that exemplifies the user's knowledge and performance.
4. Interpreting further data by an iteratively evolving model until the knowledge domains are complete.
5. The principle focus for the knowledge acquisition team should be in constructing models, in domain definition, or problem identification and problem analysis.

For HCI practitioners working as part of development teams whereby their results can lead to significant changes in design, it is important to define and incur the highest quality of empirical data captured.

By adopting digital processes, analysis of such data can be enhanced with software tools that incur faster data acquisition and processing times than humanly possible, along with large data storage and retrieval capabilities. Digital tools can therefore raise the quality of user centred knowledge elicitation and analysis. In this paper we present an approach to acquiring further cognitive user metrics within low fidelity prototyping in the HCI domain, through the use of software tools.

This paper continues as follows; in Section 2 we briefly describe low-fidelity prototyping and current software tools that are widely used. Section 3 presents a background to existing constructionist methodology, for the reader to grasp the dynamics of how constructionism links to design artefacts. As part of our framework, constructionist metrics and event patterns over the timeline history of prototyping construction are also proposed. In Section 4 we describe the iterative design and development of our tools to facilitate our framework. Section 5 outlines our experiment scenarios to validate our framework. Section 6 goes on to describe the findings of our scenario tests in order to validate our framework. Section 7 discusses our participatory design (PD) sessions to evaluate and improve our software tools, for use by HCI practitioners and educators, and finally Section 8 concludes our work with suggestions for future research in this area.

2 Low-Fidelity Prototyping

The practice of low-fidelity prototyping in HCI uses simple materials and equipment to create a paper-based simulation of views to an interface or system with the aim of exploring early user requirements and visualizing layout, accessibility and potential aesthetic approval of design ideas.

Over the years, strategies and uses of prototyping methods [Hardgrave & Wilson 1994] have grown to become a key asset in the HCI toolkit. With traditional paper and pen based approaches, it is common to denote features of a user interface with visual artefacts metaphorically described on paper, e.g. menu bars with triangles on either end, or rectangular buttons for actions. If it is being constructed with movable separate pieces of paper these artefacts allow members of a prototyping team to interact with it and easily reach a consensus on the effectiveness of position, size and purpose. It is also common to label features and visual artefacts, with annotation descriptions of their purposes and links to other artefacts.

There are numerous software painting and drawing programs available such as Windows Paint, Macromedia Flash, Adobe Illustrator, Microsoft Visio and PowerPoint, and the GIMP, to name a few in no order of preference. These artistic and diagrammatic tools can be utilized for low-fidelity prototyping and sketching of user interface designs. Recently, more HCI practitioner-orientated low-fidelity prototyping tools have been developed, including software from the GUIR team at Berkeley [Walker et al. 2002] which has produced *Denim* and *Silk* to facilitate prototyping of early stage website design. *Denim* allows low fidelity prototype sketches of website designs to be 'run' associated with hyperlink navigation to other prototype sketches akin to storyboarding. Also their *Suede* system [Klemmer et al. 2000] is a powerful speech based Wizard of Oz Prototyping tool based on speech dictation interfaces.

3 Constructionism in User-Centred HCI

3.1 Constructionist based Artefacts Modelling

Constructivist learning theory [Piaget 1973; Vygotsky 1978] argues that knowledge is not just transmitted, but is constructed. Thus we refer to the construction of new knowledge by learners themselves with sensory information and the behaviour of self-constructed knowledge that is built up through experience [Jonassen 1994].

This theory branched in the form of constructionism. Constructionism [Papert 1991; Resnick 1996] in the HCI-applicable sense is an epistemological view concerned with the reinforcement of existing user knowledge and creation of new knowledge. This is critically achieved through the use of tangible artefacts and metaphors that users can affiliate with from their sensory information and their past experience and intuitions.

Several knowledge elicitation techniques in HCI can be argued to elicit user-centred data through the use of tangible artefacts. Low-fidelity prototyping is noted, by use of paper materials and sketching individual artefacts. In addition; card sorting, affinity diagramming, brain storming and perhaps others are also constructionist. They reinforce and create new user-centred knowledge domains through iterations

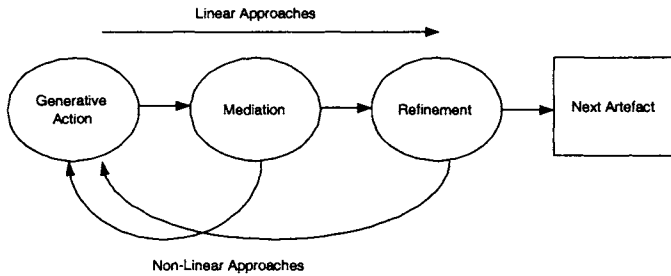


Figure 1: Linear and Non-linear approaches in artefact-driven construction.

of activity, consensus and refinement of tangible and metaphorically identifiable artefacts e.g. cards and physical objects.

These new knowledge domains are created by the users themselves constructing visibly representative artefacts during the knowledge elicitation activity. They may use what they create to further define new artefacts or redefine existing ones, and so forth. This chaining effect has already been described previously as part of the principles within Activity Theory [Leont'ev 1978; Vygotsky 1978].

In simplest terminology, 'activity' is defined as "the engagement of a subject towards a certain goal or objective" [Luria 1981; Ryder 1998]. Vygotsky contributed to Activity Theory by describing activity mediated through artefacts. In general, artefacts are both a set of constructed initial activities but they can also be a product of an activity, and can be modified throughout the timeline of an activity.

As Bertelsen [2000] denotes "Using Star's [1989] terminology, design artefacts are boundary objects because they adapt to different situations of application and at the same time maintain identity, thereby mediating divergent needs and viewpoints." Bannon & Bødker [1991] describe this format of mediation as a critical part to understanding artefacts and distinguishing them from each other. Béguin & Rabardel [2000] similarly uses this idea of mediation to explain the artefacts within the cycle of construction as a combined result of generative activity, mediation and refinement stages.

3.2 Constructionist Metrics

Here we describe an internal cognitive design cycle that demonstrates how a single artefact is created from several key stages (Figure 1):

1. Decisions (Generative Activity and first innovation).
2. Mediation (Backtracking, pausing for reflection).
3. Refinement (Assessment and innovation, leading to modifications).

Upon refinement several artefacts can become reinforced by further Decision stages, leading to subsequent branching of Mediation and Refinement within (recursive constructions). Decision making as an activity can thus branch into 3 dimensions:

Name	Type	Value	Explanation
Ta	total time	shorter time	confident but lacking mediation or in a hurry
Tb	total time	longer time	strong mediation but not necessarily confident (could be indecisive)
Aa	addition	lots, in a short time	strong confidence, instinct and implies using personal domains of knowledge
Ab	addition	few, in a short time	not confident at task, relies on mediation
Ac	addition	lots, in a long time	strong confidence, attention to detail (methodological approach)
Ad	addition	few, in a long time	not confident at task, doesn't rely on mediation
Ma	modifications	few, in a short time	strong confidence, weak mediation (possibly pre-final refinement)
Mb	modifications	lots, in a short time	mediation and refinement stages, either indecisive or debating, strong output on agreement consensus
Da	deletions	few	confident in output
Db	deletions	lots	either non-confident, or understanding/ expertise is being corrected under mediation
AM	additions and modifier pair	lots	atomic expertise — strong sense of refinement /perfectionist
MD	modifiers and deletion pair	lots	suggests mediation and resolution towards positive refinement stage
AD	additions and deletion pair	lots	either non-confident, or understanding/ expertise is being corrected under mediation

Table 1: Proposed event patterns within an internal design construct.

- Addition (First Set).
- Modification (Mutate or Get and Set).
- Removal (Delete).

In addition to these, a fourth variable exists, a ‘Mediation Point’ which we can describe as a point in time when a generative activity (Decision) halts for an arbitrary period (like a rest), and then continues onwards in the timeline with mediation and refinement either leading on to a new artefacts construction or to modification of the existing. This mediation point is important to us to distinguish sums of artefacts from a single artefact in a construct. For example, sketching a prototype view of a DVD movie menu interface may show one artefact collection as a navigation block which has icons, labels and a button style; a mediation point will separate this as one artefact before the user has considered a next artefact to be created e.g. a background menu image.

Thus several events within a generative activity can become measurable either on their own or as clusters. In Table 1 we describe several possible event patterns as

part of our framework to describe artefact driven constructionism within the temporal view of generative activities.

4 Design and Development of Framework Tools

There is a depth of user knowledge beyond which paper based methods can acquire that software tools can assist with. Existing desktop tools provide assistance to this. However in addition, mobile devices e.g. PDAs and Tablet PCs are already becoming “part of the HCI practitioner’s toolkit” — expensive toys yes, but they are slowly becoming more prevalent for multiple serious uses by HCI practitioners and educators, especially when on-demand and on-site activities require it. Therefore our approach is from the ground up designed to augment them with the techniques in software using state of the art capabilities, and enabling such techniques to be effectively taken to client-side location domains, store and process client-side HCI data efficiently.

We designed and developed two software tools with the aim of:

1. providing as close a simulacra as possible to the existing practical methodology of low fidelity prototyping in software; and
2. provide a technique for electronically automating the evaluation of our framework with the software solution provided in (1).

4.1 Software Development Platform

As a visually rich representation of low fidelity prototyping, the form of digital inking meant the need for a visually rich and high resolution interface, with strong mimicking of the existing interaction level with novel advantages in being able to maintain portability for on-site uses; a key advantage in updating current-day HCI knowledge elicitation methods given the nature of wireless networking and mobile computing options. The Tablet PC platform from Microsoft was specifically chosen as the mobile platform to host our framework in the form of the PROTEUS tool (*PRO*Totyping Environment for *U*ser-interface Studies), with a second tool, PROTEUS EVALUATOR, to assist in the analysing of artefact creation over time within PROTEUS based low fidelity designs.

The Microsoft Tablet PC Software Development Kit (SDK) with Visual Studio.Net 2003 provides rich API libraries to developing for new pen interactivity models, post normal laptop usability patterns. As a hybrid mobile device between PDA and PC, a Tablet PC’s inking facilities in particular feature well with pressure sensitivity in onscreen pen motion, pen gestures for user metaphor based event firing and real-time recognition of handwriting on visual user interface components.

4.2 Expert Iterative Design

Participatory design (PD) sessions with 4 HCI practitioners were conducted for the development of the software tools, firstly with a pre-understanding survey to elicit requirements and request for features by priority. After debate it was clearly understood and agreed that standard paper and software approaches are great for eliciting basic informal requirements. However, it was also understood that being

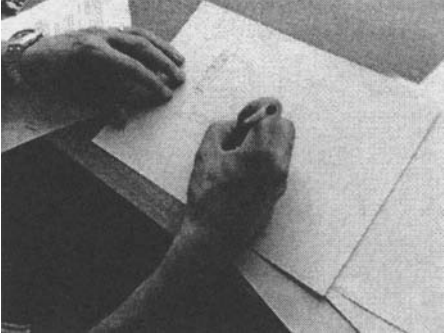


Figure 2: Expert prototyping design session of the PROTEUS tool.

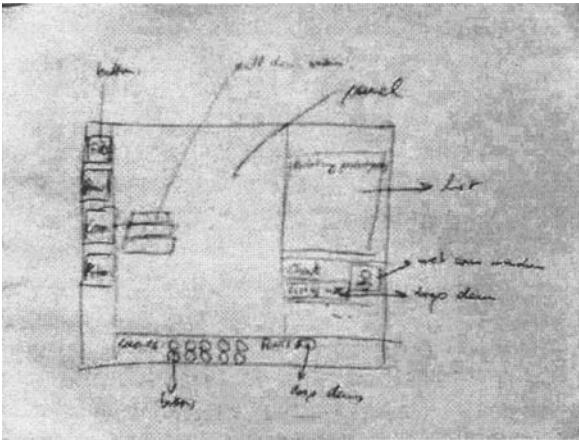


Figure 3: Example low fidelity paper prototype of the PROTEUS user interface.

able to visualize a design as changes over time and seeing decisions through the constructionism model as artefacts would reveal user knowledge and cognitive abilities that are not otherwise easily and conveniently acquired directly.

The practitioners were introduced to the concept of Tablet PC-based pen gesturing actions and onscreen handwriting recognition as a potential interface to the tool. They were also introduced to the notion of temporal analysis capturing key design artefacts being created, as per requirements of our framework. Using these requirements attributes, low fidelity paper prototypes were then created by the practitioners to elicit potential user interface designs (Figures 2 & 3) which aided us with consistency of options, navigation of incorporated tools, and investigate potential routes for minimizing user actions.

The interaction model mimics the physically tangible model of paper based prototyping as close as possible; e.g. pen sensitive drawing/selecting/erasing (pen

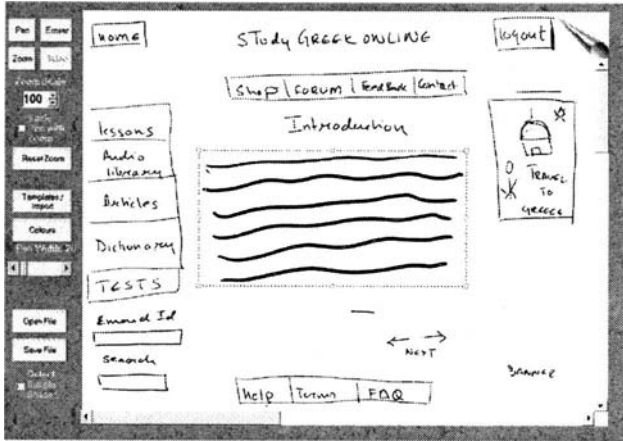


Figure 4: PROTEUS with a low fidelity prototype of a website design scenario.

down with depth for drawing), auto-selecting connected elements (pen double click motion), picking up and moving visual elements (pen drag motion on selected elements), and quick erasing (pen eraser button).

These digital pen actions have the added advantage of providing a resource of data for digitally logging all motions and actions, and record-keeping of the artefact formation in progress, as well as being fast and convenient for using a pen in a one-handed mobile or stationed environment. It also enables us to calculate in software arbitrary mediation point delays between artefacts, originally set at a default of 10 seconds. Thus after 10 seconds of inactive use, further constructs are considered to be a new artefact, mediation or a refinement.

The uses of this interaction model were explored further in individual interviews with the practitioners to gain solely their personal opinions and feature requests. This enabled us to inquire additional requirements which were agreed during a follow-up focus group session as well as (after consensus of the four HCI experts) removing and minimizing less used and potentially obstructive features. Post evaluations of the tools were conducted with design practitioners through a number of post-questionnaires which found that the users were happy for the tools to be deployed in HCI scenarios.

PROTEUS version 1.0 (Figure 4) simulates the actions of a low-fidelity paper prototype being constructed with the addition of all user events being recorded, including every pen stroke and user interface choice via SDK GUID calls. Using this data it constructs temporal roll-back views of the prototypes creation so that every action of manipulation of the virtual paper prototype can be evaluated at a later date to elicit potential weaknesses or strengths at prior stages of the prototype design process.

The time indexed ink-encoded GIF file output (serialized from the Tablet PC SDK) can be shared with others and imported into existing designs as prototype

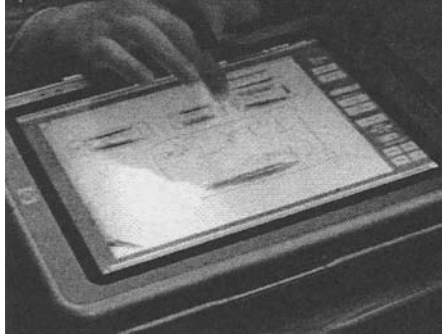


Figure 6: PROTEUS on a Tablet PC in use during the student scenarios.

Throughout these expert trials they could raise any points of interest or complaints. Finally a post-test Quality of User Interface Satisfaction questionnaire (QUIS) Chin et al. [1988] was given to collect information about their general impressions about the tools and any modifications they thought were necessary. From the data collected, a number of key user interface issues such as menu options, accommodating appropriate pen-sized interface actions, interface terminology, button styles and integrated help requirements were modified into subsequent builds.

5 Experimental Scenario Testing

In order to better understand the application of constructionist assessment in prototyping, it was decided that scenario testing of the tools and the framework would be undertaken with 40 postgraduate MSc participants recruited from an Advanced HCI class module. This would enable us to compare the constructionist framework of artefacts analysis with an existing expert HCI marking methodology.

The participants were invited to utilize the PROTEUS tool in two scenarios for the design cycle of an online language learning website, and a novel interface to a train ticket machine. Working in groups of 5–7, they utilized 4 Tablet PCs (1GHz+, each with 512Mb RAM running Windows Tablet PC 2005) in turns in a classroom location. Whilst one half of the class used the well-established paper format for one scenario, the same scenario was being completed with the software tools by the other half of the class.

At the second scenario, the students switched methods from paper to software and vice versa (Figure 6). Each scenario was given 20 minutes to complete the task. Upon completion of their prototypes, the different groups were shown the others solutions to demonstrate the variety of prototyping ideas that groups can give using low fidelity prototyping in practice.

For HCI lecturers, practitioners and researchers, the methodologies for evaluating practical paper and software based forms of low fidelity prototyping are fairly similar in acquiring key user requirements, eliciting more of the conceptual basis and creativity of ideas than precision in style. Understanding the user's

Low-Fidelity Prototyping Expert Assessment Criteria	
1	Use of colours and variety of pens to distinguish elements
2	Demonstrating a sense of proportions and scale
3	Use of simple shapes to denote complex objects
4	Representation consistency in reuse of shapes and colours
5	Use of contextual language, annotation and terminologies
6	Ease of 3rd party understanding of the users' representations
7	Aesthetics awareness and use of layout, usability design
8	Ideas and innovation presented to the domain proposed
9	Context of design and accessibility to domain proposed
10	Overall quality of effort

Table 2: Our department's low fidelity prototyping expert assessment criteria.

mental models also gives us useful data centring on the usage of appropriate design metaphors and the achieving key tasks for functionality. Table 2 shows our department's expert assessment criteria as used to evaluate paper prototype courseworks from an Advanced HCI MSc class.

These expert criteria can only determine metrics of user mental models with a final prototype design view and does not elicit qualitative measures that may have been significant within the duration of the prototype's timeline. Hence, it is this data which can be compared with that of our framework, which can give additional qualitative measures over the temporal construction of the prototype design.

6 Scenario Results

Expert marking evaluations of the prototypes were conducted with two HCI practitioners marking the software based views, and a different two HCI practitioners marking the paper views, such that bias of software against paper expert comparisons could be avoided.

No statistical significance was found between the expert quality marks of paper version prototypes to the expert quality marks of software version prototypes ($t_{11} = 1.68, p > 0.05$). This indicates that using the Tablet PC software was not a negative influence on the practical methodology of low fidelity prototyping. However, a second t -test of Scenario 2's outputs alone (software vs. paper) demonstrates $t_5 = 3.13, p < 0.013$. This indicates the software method was preferred than the paper method and this may show that the effectiveness of using such digital tools is potentially dependent on the scenario of use. As shown in Figure 7 mean marks for the second scenario (ticket machine interface) were higher than those of the first scenario (language learning website), with inferences to using more creative scenario ideas. We suspect the variety of pen options in the software aided in eliciting this higher creativity quality.

To evaluate the constructionist data, our PROTEUS EVALUATOR tool generates Excel compatible spreadsheets directly from the time encoding of events that occurred within the creation of the ink-encoded GIF files from the software sessions.

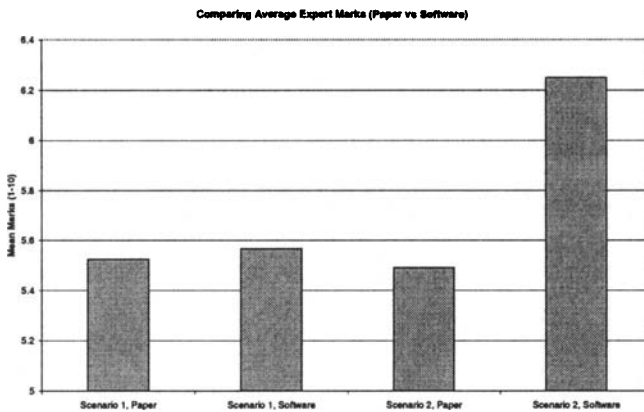


Figure 7: Paper vs. Software expert marking for the two scenarios.

This allows us to compare electronically generated results of the software based prototypes in terms of artefact-driven confidence vs. the independent expert markers evaluations; Figure 8 shows some of the automated results of artefact-driven constructs assessment vs. expert HCI marking. The expert marks were awarded out of 100% based on the assessment criteria defined in Table 2.

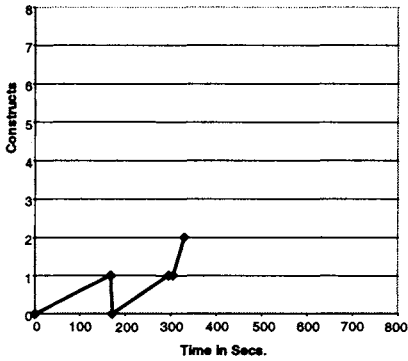
The use of the PROTEUS EVALUATOR tool to analyse the constructions of artefacts within the users PROTEUS based prototype designs determined several key points in our experiments:

- Confident groups spent less time in refinement stages.
- Low values of generative activities obviously imply either non-enthusiasm or inability to construct confident and positive design artefacts.
- The average interval time between mediation points involving modifications has been found to be considerably shorter than additions and deletions, we suspect due to mediation (reflecting on choices made) and refinement (assessing possible outcomes) giving a clearer idea of what to manipulate.
- Successive generative activities indicate sources of innovation.

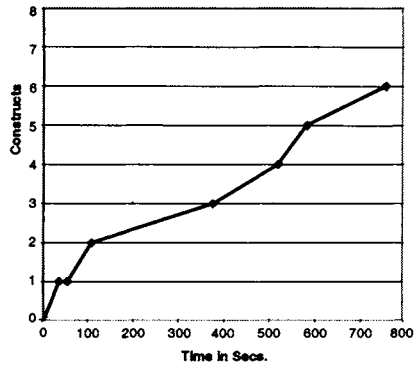
Weaker teams in terms of expert marking criteria measured longer decision-mediation-refinement cycles before considering creating new artefacts.

7 Users Evaluation of the Tool

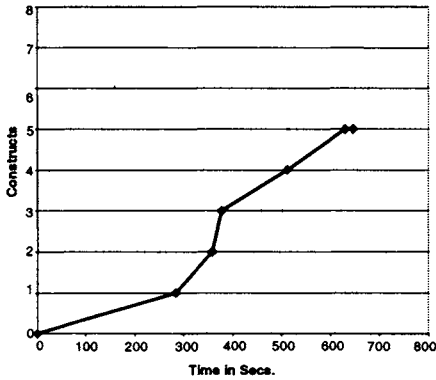
After the scenario testing, a full scale post questionnaire based on the User Satisfaction QUIS [Chin et al. 1988] questionnaire was filled by the 40 student participants. This QUIS is based on a 0 to 9 Likert scale for a variety of categories, as shown in Figure 9. Subsequently, an ease-of-use post questionnaire based on the



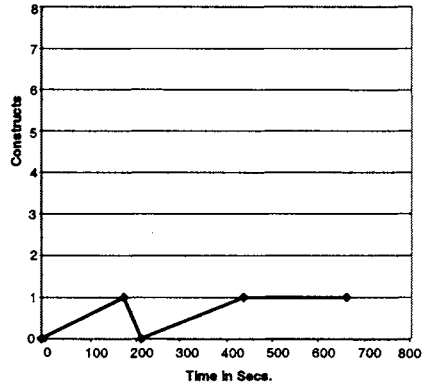
(a) Scenario 1, Team 2: experts awarded 46%; software detected 5 mediation points, over a short time period, with little mediation/ refinement time in between.



(b) Scenario 1, Team 5: experts awarded 61%; 7 mediation points detected in software, with long periods of generative activity indicating thoughtful team consensus.



(c) Scenario 2, Team 1: experts awarded 70%; 6 mediation points detected, with little mediation time in between rapid generative activity, possibly indicating confidence in design.



(d) Scenario 2, Team 5; experts awarded 52%, 4 mediation points detected, little generative activity but long mediation, an indecisive team.

Figure 8: Artefact constructs detected with PROTEUS EVALUATOR vs. Expert marking.

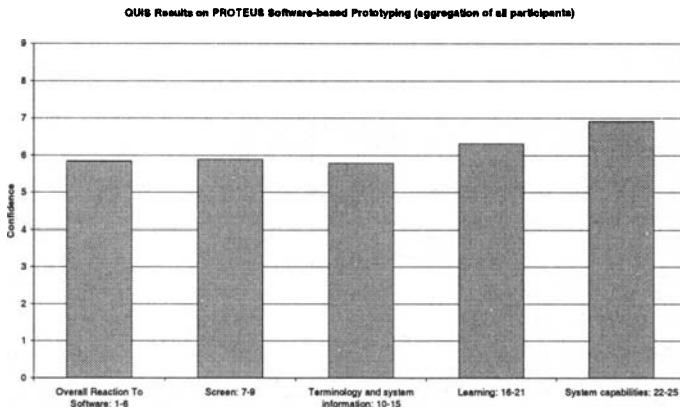


Figure 9: QUIS results on user interface satisfaction.

CSUQ questionnaire Lewis1995 was conducted with additional questions to indicate personal preferences between software and paper methods.

In both of QUIS and CSUQ questionnaires, the PROTEUS tool was rated above average in all questionnaire categories. A mean of 82% of the users stated that they found the tool was comparable, if not better than the existing paper practice. 69% of users felt that the tool gave them new capabilities in the sense they only expected these features within a mouse-desktop paint/diagrammatic program and not within the natural feel of a pen-based direct inking tool. 89% of participants felt that the tools and software options provided covered the interaction level sufficiently to facilitate productive low-fidelity prototyping in the HCI context.

8 Conclusions and Further Work

We have provided an example of our framework for electronically evaluating otherwise complex user confidence and capability issues from observing the construction of artefacts in prototyping, as an additional measure to existing low fidelity evaluation. Our contributions are as follows:

- We have constructed a specific HCI software solution, PROTEUS, which enables the major functional requirements of low fidelity prototyping to be captured via a mobile device, in the form of a Tablet PC; this enables on-site elicitation and digital recording and sharing of prototypes.
- We have developed a second tool, PROTEUS EVALUATOR, to assist in analysing design artefacts and constructionist data in the timeline of PROTEUS designs. This has led to the exploration of using the artefact-driven constructionist theory to create a working model of artefact driven assessment metrics. This forms a research opportunity for mapping potential

cognitive decision making characteristics within the temporal creation of user knowledge elicitation.

- Finally we have conducted two scenario driven experiments using our framework with PROTEUS, and compared data with expert formal assessment guidelines, to demonstrate links with the existing methodology.

For HCI practitioners and educators, existing paper based prototyping methods are obviously quick, cheap and practical if the space and materials are available. Low-fidelity ideas are captured efficiently this way. However, their outputs are not effectively recorded on paper in a consistent and shareable form, and intermediate decisions made are not easily recorded on paper (e.g. how they arrived at particular artefacts that are consistently used metaphorically in their design and what potential decisions did they make along the way), nor is the final output completely indicative of the personal confidence, initiative and capability of the user(s) involved. Automating the collection of this data in readily usable formats is seen as a beneficial capability. For the advancement of practical HCI methodology there is an advantage especially so for HCI educators to be realized here with such tools.

We would like to see this work expanded further and applied to other scenarios. In particular we intend to continue to map further cognitive measures within artefacts, e.g. expanding on the clustering of multiple constructionist event types (Table 2). We believe similar techniques can be applied to other knowledge elicitation methods such as affinity diagramming and card sorting which also use constructionist ideals.

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