Designing Virtual Environments for Usability

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Submitted for Examination of Doctor of Philosophy

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London

June 1998

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Appendix 4A: A description of stages in task action mode, with the corresponding Norman cycle stages

Stage	Norman stage(s)	Description
establish goals	*form goal*	Formulate high level goal to drive interaction. Implications from the evaluation of finished actions are taken into consideration. The goal may be new or one retrieved from the backlog of unachieved goals. The established goal is output to the next stage.
intention task action	*form intention*	Formulate next action to carry out. The action will help fulfil the current goal, input from previous stage, and implications from the evaluation of finished actions will be taken into consideration. The intended action is output to the next stage.
consider objects	*specify action sequence*	Determine objects or environment section of interest to the current action. Objects of interest will often be those acted upon to complete the action. Where the action is not very explicit, such as for a learning task, broad sections of the environment may be relevant. If the target objects do not have to be searched for in the environment, i.e. their location is known and they are in immediate vicinity, then information about the action on the target will be output to the next stage. Otherwise, target information is passed on to explore/navigate mode where the target may be searched for. Where there are no clear objects of interest, only broad sections of the environment, information about these sections will be passed to explore/navigate mode where they can then be scanned and target objects of interest chosen for opportunistic actions.
approach /orient	*specify action sequence, execute action, perceive world state, interpret world state*	Approach target in vicinity and suitably orient self to target. This operation is a precursor to a possible object manipulation and being a sub-part of the action the four Norman stages involved have been grouped into one stage. The action sequence required for the approach and orientation will need to be determined. The approach can then be executed and resulting changes in the environment can be perceived and interpreted. The approach can be retried where the result is not satisfactory. The target to approach is input from either a) the previous stage, when the target did not need to be searched for, or b) explore/navigate mode after searching and finding the target, or c) explore/navigate mode after planning to carry out an exploratory action on a target of interest, or d) system initiative mode after planning to carry out a reactive action on objects involved in system behaviour. In cases b), c) and d) when a target of interest is found, behaviour changes from exploratory or reactive mode to task action mode in which planned actions are carried out on the target in a systematic way and evaluated. Exploratory and reactive actions are transferred to task action mode because, once an intention has been formed, the processing required for the different action types is essentially the same. If further interaction on the target is not to be carried out, information about the recognised target is passed to the inspection stage, where the object can be inspected. When the target object is to be manipulated in some way, information about the action on the approached target is passed on to the next stage where the manipulation can be specified.

deduce sequence	*specify action sequence*	Specify sequence of operations required to carry out object manipulations for the intended action. The determined interaction sequence will be output to the next stage.
execute	*execute action*	Perform the object manipulations using the interaction sequence input from the previous stage. The environment state is altered by the manipulations and information about the executed interaction passed on to the next stage.
feedback	*perceive world state, interpret world state*	Understand the feedback available from the environment with respect to the executed action. Information about the recognition of the feedback is passed on to the evaluation stage. This stage corresponds to two Norman stages, perception and interpretation of the world state, so that understanding of the world state can be modelled in one direct stage.
inspect	*perceive world state, interpret world state*	Obtain required information from approached target by inspecting it. Information about the inspected object is passed to the next stage.
evaluate	*evaluate outcome*	Assess implications of interpreted environment state for the ongoing task. The interpreted world state originates from either a) the inspected object from the previous stage, or b) the recognised feedback from the 'feedback' stage, or c) an interpretation of an environment-triggered behaviour from the system initiative mode. In the latter case, behaviour changes from reacting to system behaviour in system initiative mode to task action mode, where the behaviour is checked against ongoing task objectives and any important implications determined. If the implications of the world state affect the ongoing task at a high level then information about the implications is passed back to the first stage where the goals can be re-established with respect to the latest action/event. If the ongoing task is affected at a lower level, information about the implications is passed back to the second stage where intentions to act can be formed or re-formed.

Appendix 4B: A description of stages in explore navigate mode, with the corresponding Norman cycle stages

explore	*form goal, form intention*	Establish will to explore. Areas of interest may be determined or the exploration may be wholly undirected with no prior information about targets. Information about the intention to explore is output to the next stage. This stage corresponds to two Norman stages because the forming of exploration objectives is not complex enough to warrant two individual steps; the intention will typically be ill-defined.
scan	*perceive world state, interpret world state*	Inspect current state of environment from available output. The inspection will be informed by either a) information about an intention to explore input from the previous stage, or b) information about a target to be searched input from task action mode, or c) where there is a re-scan after navigating, the scan will be informed by the current intention to explore from the navigate stage, which may involve a target search. This stage corresponds to the two Norman stages following system output, because interaction will be driven by the current environment state. Information about the results of the scan, such as detected or recognised objects, is output to the next stage.
plan	*evaluate outcome, form goal, form intention*	Determine appropriate plan of further activity from inspection of present environment state, with respect to either the target search or the exploration intention. This stage corresponds to Norman stages of evaluation and goal/ intention formation. An evaluation is required to assess implications of the inspection for an ongoing exploration or search task. Given this a suitable response can be determined. These three steps coherently form one stage in this model. If a target, from task action mode, has been found then information about the recognised target can be passed back to task action mode where the previous intention to act can be re-established and the target acted upon accordingly. Whilst scanning the environment, if a feature arouses interest then information about the feature can be passed forward to the exploratory action stage. Features can arouse interest whilst searching for a target. If no features arouse interest and a target has not been found then the scan has been unfruitful and an intention to explore further is re-established taking into account any target search and possible changes to areas of interest for exploration, from experience with the environment. Information about this intention is passed on to the next stage.
navigate	*specify action sequence, execute action*	Move self to a location elsewhere in the environment. This movement can include view angle changes. An intention to explore further is used as input to inform the move. It may include information about a target to search, or it may be an open intention to explore with perhaps specific areas of interest. Prior to executing the navigation, the sequence for navigation is specified, such as the navigation technique. Usually the navigation will stop when a sufficiently new environment output is available so that the environment can be re-scanned. Information about the current intention to explore is then passed back to the scan stage. This navigation-scan loop can continue whilst there remains an intention to explore. This stage corresponds to two Norman stages because navigation will be a commonly executed action and the sequence for navigating is likely to become well-learned and require little conscious processing.

intention explore action	*form intention*	Formulate action to carry out on a feature of interest. Where a feature arouses sufficient interest then an exploratory or opportunistic action will be carr'ed out. Exploratory actions are those which are carried out to gain knowledge about the nature of objects in the environment and opportunistic actions are carried out when possibilities for interaction are discovered whilst exploring and there is a desire to try out the action. Information about the feature will be input from either a) the plan stage, or b) system initiative mode when system behaviour is seen to require further investigation and interaction therefore switches to exploratory mode. A specific intention to act on the feature is established in this stage. The intention will already include involved objects because the intention has been driven by interest in particular environment objects rather than being driven by a need to fulfil task goals, as in task action mode. Information about the exploratory action is output to task action mode, where the target object may next be approached and the action carried out. An exploratory action may involve only examination of the object and no object manipulation but behaviour is described as switching to task action mode because it is a planned action, which will be carried out and evaluated with respect to intentions and overall goals.

Appendix 4C: A description of stages in system initiative mode, with the corresponding Norman cycle stages

event	*perceive world state, interpret world state*	Perceive event and establish some understanding of it. The event is triggered by a system agent and not by this particular user. The event attracts attention and information about it is available from the environment. An interpretation of the event is output to the 'plan' stage. This stage corresponds to the two Norman stages following system output, because interaction will be driven by environment event(s).
acknowledge control	*perceive world state, interpret world state*	Realise and accept that system has taken control over interaction. Information about the commencement of system control is available from the environment. An interpretation of the system control is output to the next stage.
monitor	*perceive world state, interpret world state*	While system control continues, monitor system behaviour. Information about the commencement of system control is passed from the previous stage and information about continuing system behaviour is available from the environment. During this stage, an interpretation of monitored system behaviour can be output to the next stage to assess whether user control can/should be exercised. Otherwise, system behaviour is continually monitored until the end of system control, when an interpretation of monitored system behaviour is output to 'end control' stage.
intention control action	*interpret world state, form goal, form intention*	Form intention to carry out action to exercise user control, using information about the monitored system behaviour passed from the previous stage. There may be cases when the system takes control but the user can still carry out actions, such as navigating or even terminating system control. If user activity is thought to be possible and there is motivation for activity on the part of the user then an intention to exercise user control is formed and information passed to task action mode, where the action can be attempted. Else processing continues at the 'monitor' stage. Having formed an intention to exercise user control, interaction may soon return to system initiative mode when information about the continuation or termination of control is interpreted. The Norman stages used refer to interpretation of the system to ascertain whether user activity is possible and then, where possible, decisions as to whether to exercise user control.
end control	*perceive world state, interpret world state*	Realise that system control has terminated and control is now returned. Information about the termination of system control is available from the environment. Information about the monitored system behaviour, passed from the 'monitor' stage, is output to the next stage.

plan	*form goal, form intention*	Determine appropriate plan of how to deal with system behaviour. System behaviour can be either system initiative events, occurring at a point in time, or system behaviour during system control, over an extended period of time. Information about system behaviour is input from either a) 'event' stage on interpretation of a system event, or b) the previous stage on termination of system control. Unlike the plan stage in exploration mode, the Norman evaluation stage is not included because there is no ongoing goal or intention that is considered in this behaviour mode. If the system behaviour is perceived to be significant to the ongoing task, or there is uncertainty as to its significance, then information about the behaviour will be passed to task action mode where it will be evaluated against any interrupted goals and intentions, and against the ongoing task in general. If the behaviour is immediately seen to require necessary reactive action then information about it will be output to the next stage. This applies more to system events than behaviour during system control because such behaviour will tend not to have an immediate reactive response. Alternatively, if there is interest in the behaviour and further information about it is desired, then information will be passed to exploration mode where an exploratory action on objects involved in system behaviour can be proposed. Finally, if the behaviour is not seen to be significant to the ongoing task, and if there is no interest in it or sufficient knowledge about it, then the behaviour may be ignored.
intention reactive action	*form intention*	Formulate action to carry out, to react to system behaviour. Information about the behaviour will be input from the previous stage. A specific intention to act on involved objects is established in this stage. Information about the reactive action is output to task action mode, where the target object may next be approached and the action carried out.

Appendix 4D: A description of the generic design properties

Note: Examples for each GDP can be found in appendix 6A, which lists design guidelines developed from the GDPs.

KEY: GDP types
BS – Basic Supports; *IP* – Information Providers

Category	Generic Design Property	Description	Type
User task	**action support for task**	Actions required to complete the user task are available and can be carried out according to the structure of the user's task. Components involved in the user task are present in the environment.	*BS*
	relevant content, actions and system behaviour	The environment content, its available actions and any system events and system control are relevant to the user task. Time will not be wasted with the user being distracted and exploring when there is little relevance to their overall goals.	*BS*
	clear task/ task flow	The user's task in interacting with the environment is clearly defined and the steps required in performing the user task are clear.	*IP*
	clear task components	It is clear what components are involved in the user's task actions.	*IP*
	clear task state	Information is readily available about the state of the user task, i.e. completed goals and unfulfilled goals. Any changes to the task state are clearly presented.	*IP*
Overall Environment	**discernible *environment* content set**	The general contents of the whole environment can be *easily determined.*	*IP*
	discernible repertoire of opportunities for action	The general opportunities for user action within the whole environment can be easily determined. This includes information about constraints on opportunities for action within the environment.	*IP*
	declared areas of interest	It is clear which are the main or significant parts from the whole environment (areas, objects and actions). The significant parts draw attention to themselves and the insignificant parts are less conspicuous. Areas of interest can be with respect to the user task and/or inherent in the environment.	*IP*
Spatial knowledge	**clear current area**	The part of the environment currently perceivable and, therefore, in which the user is located, is clear.	*BS*
	environment enclosure	There is a clear spatial boundary to the environment and the user cannot take position outside the scope of the environment.	*BS*
	discernible spatial structure	The overall layout of the environment can be easily determined.	*IP*
	locatable object/ areas of interest	Important objects and areas of interest can be easily located, from anywhere in the environment.	*IP*
	identifiable optimal routes	The best (easiest, shortest) routes to destinations can be easily determined.	*IP*
	clear visited areas	It is clear what areas in the whole environment have been visited and what areas are new or unvisited.	*IP*

Objects	**distinguishable object/ object parts**	Objects present in the immediate vicinity can be easily distinguished and significant parts of the objects can be distinguished, from any viewpoint. Object representations are distinctive with clear boundaries. Inherent, ongoing behaviour of the object can be perceived, e.g. rotations of planets.	*BS*
	identifiable object/ object parts	The object and its parts can be readily and reliably identified. If the object is copied from real world phenomena, then its representation is accurate and matches user expectations.	*IP*
	clear object role	The purpose or function of the object in the environment is clear. Relationships with other objects are clear.	*IP*
	clear object type/ significance	The class of the object - feature, passive object, active object or agent - is clear. The interactivity and relative importance of the object, in the environment and to the user task, is clear.	*IP*
	clear object state	The state of a changeable object is clear. The parts signifying the object state are visible and identifiable.	*BS*
	clear object position/ orientation	The relative position and orientation of the object is clear.	*BS*
	accessible object	The object can be easily accessed, i.e. the user can closely approach the object and take up a suitable position/ orientation to it.	*BS*
Viewpoint & user representation	**detectable self parts**	The parts making up the user representation (self) can be easily located from any orientation, and can be distinguished from the rest of the VE.	*BS*
	identifiable self parts	Parts of the self can be readily identified.	*IP*
	clear self parts role	The role and functionality of the self parts are clear. In particular, it is clear what actions are associated with the self parts.	*IP*
	clear navigation pathways	The valid paths through the current part of the environment are clear, i.e. parts of the environment in which the self can travel through and take position.	*IP*
	clear self position/state	The present position, orientation and posture of the self is clear. This incorporates the 3D position and angle from where the environment is perceived, and the position of individual self parts. The state in which the self is in if this can change, is clear.	*BS*
System behaviour	**declared system control commencement/ termination**	It is clear when the system takes control of the interaction and later when control is returned to the user.	*BS*
	clear system control purpose	The goal of the system in controlling the interaction is clear. There is some indication to the user when control may be returned to them.	*IP*
	declared available actions during control	It is clear what, if any, actions are available to the user whilst under system control.	*IP*
	limited system control	There is not excessive system control, so the user can actively explore the environment.	*BS*
	distinguishable behaviour	The event or system behaviour can be perceived and represented in the environment and can be distinguished Where stimulus is provided from different modalities it is coherently integrated	*BS*

	declared causality and effects of behaviour	The contextual meaning of the system activity is clear and unambiguous. The cause, involved objects and resulting effects of the system behaviour are clear.	*IP*
	clear system activity significance	The relative importance of the event or system behaviour with respect to the environment and user task is clear. This includes temporal urgency of an event and its duration and repeatability.	*IP*
	appropriate response to system activity	The appropriate response(s) to the system activity is clear, such as whether it can be ignored or needs further investigation. The required reactive action for system events, where necessary, is clear.	*IP*
Actions	**declared available action**	It is clear that the potential for action exists, in the current part of the environment.	*IP*
	clear action purpose	The meaning and resulting effect of the action are clear and unambiguous. Therefore, the relevance of the action to user goals is clear.	*IP*
	declared action components	The environment components involved in the action, i.e. those acted upon or used to carry out the action, are clear. This includes self parts, objects/object parts and external input/output devices.	*IP*
	clear self/object orientation for action	The required orientation for action objects with respect to the self is clear.	*IP*
	declared action sequence	The sequence of operations required to carry out the action are clear. The links between involved components are clear.	*IP*
	executable action	The action can be executed efficiently and without frequent obstacles/problems. The action sequence is as simple as possible, not including unnecessary operations or complexity. The demand of manipulation precision and motor co-ordination is within usual human ability.	*BS*
	reversible action effect	The effect of the action can be easily undone.	*BS*
Feedback	**clear action progress**	Feedback on effects of the action, while it is being carried out, is represented and can be easily distinguished , i.e. the user can assess progress when carrying out the action. The feedback is timely and accurate and, where feedback is provided across different modalities, it is coherently integrated. This is especially important for long or slow motions.	*BS*
	clear during action effects	The contextual meaning of the during-action feedback is clear and unambiguous. The effect of device operations on the self and the effect of self operations on objects is clear. Commonly expected feedback, when real world phenomena has been copied, is included.	*IP*
	declared feedback components	It is clear what components (self parts and objects/object parts) will represent the action feedback, i.e. where in the current part of the environment to detect change. If feedback is remote, i.e. not in the current part of the environment, then this is clear.	*IP*
	declared action effect/ success	Feedback on the effect of he executed action is immediately represented and can be easily distinguished. It is clear the environment changes are associated with the executed action. The success of the action execution can be readily determined and errors can be easily detected. Where feedback is provided across different modalities, it is coherently integrated.	*BS*

	clear action effect	The contextual meaning of the action feedback, i.e. the effect of the action in the environment, is clear and unambiguous. Commonly expected feedback, when real world phenomena has been copied, is included.	*IP*

Appendix 4E: Correspondence rules for problem prediction

The correspondence rules predict problems by interaction behaviour model and, within this, the stage of interaction. A text explanation is given for the first five rules only, since all the rules follow the same format.

KEY:
AMI – Available and Matching Information function
RI – Relevant Information
KS – Knowledge sources: Environment Model (EM), Domain (D), Task (T), Real World (RW), Other Environments (OE)
GDP – Generic Design Property of Environment Available
PP – Predicted Problem

T/A: general

A user may have difficulty carrying out their original task as intended if the design does not adequately support their task. For example, it should include required actions and objects.

1 IF (NOT **GDP***(action support for task)*)
THEN **PP** = *(difficulty carrying out task as intended)*;

T/A: establish goals

A user may have difficulty establishing a clear goal for the interaction session if there is not consistent information available about their task, or they are unclear about the current state of their ongoing task, or there is not consistent information available about what kinds of tasks and actions can be carried out in the environment.

2 IF (NOT **AMI**(**RI***(task goals)*, **KS***(T)*, **GDP***(clear task/ task flow)*))
OR (NOT **AMI**(**RI***(task progress)*, **KS***(T)*, **GDP***(clear task state)*))
OR (NOT **AMI**(**RI***(opportunities for action in environment)*, **KS***(EM,D)*, **GDP***(discernible repertoire of opportunities for action)*))
THEN **PP** = *(difficulty establishing clear goal)*;

T/A: intention to act

A user may have difficulty establishing a clear intention to carry out a specific action if there is not consistent information available about their task in interacting with the environment, or they are unclear about the current state of their ongoing task, or there is not consistent information available about what kinds of tasks and actions can be carried out in the environment.

3 IF (NOT **AMI**(**RI***(task actions)*, **KS***(T)*, **GDP***(clear task/ task flow)*))
OR (NOT **AMI**(**RI***(task progress)*, **KS***(T)*, **GDP***(clear task state)*))
OR (NOT **AMI**(**RI***(opportunities for action in environment)*, **KS***(EM,D)*, **GDP***(discernible repertoire of opportunities for action)*))
THEN **PP** = *(difficulty establishing clear intention to act)*;

T/A: consider object(s) or environment part involved

A user may have difficulty determining what environment components are involved in the action to be carried out if there is not consistent information available about the components involved in this task action, or there is not consistent information available about the components that are present in the environment.

4 IF (NOT **AMI**(**RI***(action components)*, **KS***(T,EM,RW)*, **GDP***(clear task components)*))
OR (NOT **AMI**(**RI***(available environment components)*, **KS***(EM,D)*, **GDP***(discernible environment content set)*))
THEN **PP** = *(difficulty determining environment components involved in action)*;

A user may have difficulty d termining whether target objects for the current action should be in their immediate vicinity or require searching if there is not consistent information available about the location of the target object or environment area of concern, or if the design does not make clear what part of the environment is currently perceivable or in view.

5 IF (NOT **AMI(RI***(target location)*, **KS***(EM,D,T)*, **GDP***(locatable object/ areas of interest target)*))
OR (NOT **GDP***(clear current area)*)
THEN **PP** = *(difficulty determining whether target should be in immediate vicinity or require searching)*;

6 IF (NOT **GDP***(distinguishable object/ object parts - target)*)
THEN **PP** = *(difficulty distinguishing target that should be in immediate vicinity)*;

7 IF (NOT **AMI(RI***(identification information for target)*, **KS***(EM,D,RW)*, **GDP***(identifiable object/ object parts - target)*))
THEN **PP** = *(difficulty identifying target that should be in immediate vicinity)*;

T/A: approach and orient

8 IF (NOT **AMI(RI***(required object and self orientation)*, **KS***(EM,T,D,RW)*, **GDP***(clear self/ object orientation for action)*))
THEN **PP** = *(difficulty determining required object/self orientation for action)*;

9 IF (NOT **GDP***(clear self position/state)*)
THEN **PP** = *(difficulty determining current self position and orientation)*;

10 IF (NOT **GDP***(clear object position/ orientation)*)
THEN **PP** = *(difficulty determining current object position and orientation)*;

11 IF (NOT **AMI(RI***(procedure for navigation)*, **KS***(EM,OE,RW)*, **GDP***(declared action sequence navigation)*))
OR (NOT **AMI(RI***(available navigation pathways)*, **KS***(EM,D,RW)*, **GDP***(clear navigation pathways)*))
THEN **PP** = *(difficulty determining how to execute object approach)*;

12 IF (NOT **GDP***(executable action - navigation)*)
OR (NOT **GDP***(accessible object - target)*)
THEN **PP** = *(difficulty executing object approach effectively and efficiently)*;

13 IF (NOT **GDP***(clear action progress - navigation)*)
OR (NOT **AMI(RI***(semantics behind feedback received while carrying out navigation)*, **KS***(EM,OE,RW)*, **GDP***(clear during action effects navigation)*))
THEN **PP** = *(difficulty assessing progress in object approach)*;

14 IF (NOT **GDP***(declared action effect/ success navigation)*)
OR (NOT **AMI(RI***(semantics behind feedback received after navigation)*, **KS***(EM,OE,RW)*, **GDP***(clear action effect - navigation)*))
THEN **PP** = *(difficulty assessing success of object approach)*;

15 IF (NOT **AMI(RI***(self parts used during posture/orientation change)*, **KS***(EM,OE,RW)*, **GDP***(declared action components - self posture/orientation change)*))
OR (NOT **AMI(RI***(semantics for parts making up self and available self actions)*, **KS***(EM,OE RW)*, **GDP***(clear self parts role)*))
THEN **PP** = *(difficulty determining self parts involved in posture/orientation change)*,

16 IF (NOT **GDP**(*detectable self parts)*)
OR (NOT **AMI**(**RI**(*self identification information),* **KS**(*EM,OE,RW),* **GDP**(*identifiable self parts)*))
THEN **PP** = *(difficulty identifying self parts involved in posture/orientation change)*;

17 IF (NOT **AMI**(**RI**(*procedure for self posture/orientation change),* **KS**(*EM,OE,RW),* **GDP**(*declared action sequence - self posture/orientation change)*))
THEN **PP** = *(difficulty determining how to execute self posture/orientation change)*;

18 IF (NOT **GDP**(*executable action - self posture/orientation change)*)
THEN **PP** = *(difficulty executing self posture/orientation change efficiently and effectively)*;

19 IF (NOT **GDP**(*clear action progress - self posture/orientation change)*)
OR (NOT **AMI**(**RI**(*semantics behind feedback received while carrying out self posture/orientation change),* **KS**(*EM,OE,RW),* **GDP**(*clear during action effects - self posture/orientation change)*))
THEN **PP** = *(difficulty assessing progress in self posture/orientation change)*;

20 IF (NOT **AMI**(**RI**(*self parts where posture/orientation change feedback will be represented),* **KS**(*EM,OE,RW),* **GDP**(*declared feedback components - self posture/orientation change)*))
OR (NOT **GDP**(*detectable self parts)*)
THEN **PP** = *(difficulty determining where to check for self posture/orientation change feedback)*;

21 IF (NOT **GDP**(*declared action effect/ success - self posture/orientation change)*)
OR (NOT **AMI**(**RI**(*semantics behind feedback received after self posture/orientation change),* **KS**(*EM,OE,RW),* **GDP**(*clear action effect - self posture/orientation change)*))
THEN **PP** = *(difficulty assessing success of self posture/orientation change)*;

22 IF (NOT **AMI**(**RI**(*operations within action),* **KS**(*T),* **GDP**(*clear task/ task flow)*))
THEN **PP** = *(difficulty determining whether further interaction required)*;

23 IF (NOT **AMI**(**RI**(*actions available with target object),* **KS**(*EM,D,RW),* **GDP**(*declared available action - actions on target)*))
(NOT **AMI**(**RI**(*interactivity of target object),* **KS**(*EM,D,RW),* **GDP**(*clear object type/ significance - target)*))
THEN **PP** = *(difficulty determining whether further interaction possible)*;

T/A: deduce sequence for interaction

24 IF (NOT **AMI**(**RI**(*object and self parts used during action),* **KS**(*EM,T,RW),* NOT **GDP**(*declared action components)*))
OR (NOT **AMI**(**RI**(*function of parts making up self),* **KS**(*EM,OE,RW),* **GDP**(*clear self parts role)*))
OR (NOT **AMI**(**RI**(*function of available objects),* **KS**(*EM,D,RW),* **GDP**(*clear object role)*))
THEN **PP** = *(difficulty determining parts involved)*;

25 IF (NOT **GDP**(*detectable self parts - parts used for action)*)
OR (NOT **AMI**(**RI**(*self identification information),* **KS**(*EM,OE,RW),* **GDP**(*identifiable self parts - parts used for action)*))
OR (NOT **GDP**(*distinguishable object/ object parts - parts used for action)*)
OR (NOT **AMI**(**RI**(*object parts identification information),* **KS**(*EM,D,T,RW),* **GDP**(*identifiable object/ object parts - parts used for action)*)
THEN **PP** = *(difficulty identifying parts involved)*;

26 IF (NOT **AMI**(**RI**(*procedure for action),* **KS**(*EM,T,RW,OE),* **GDP**(*declared action sequence)*))
THEN **PP** = *(difficulty determining how to execute action)*;

T/A: execute object interaction

27 IF (NOT **GDP**(*executable action*))
THEN **PP** = (*difficulty executing action efficiently and effectively*);

28 IF (NOT **GDP**(*action support for task - required action unavailable*))
OR (NOT **AMI**(**RI**(*actions part of/not part of task*), **KS**(*T*), **GDP**(*clear task/ task flow - clear this action not part of task*)))
OR (NOT **AMI**(**RI**(*opportunities for action in environment*), **KS**(*EM,D*), **GDP**(*discernible repertoire of opportunities for action*)))
OR (NOT **AMI**(**RI**(*interactivity of object*), **KS**(*EM,T,D,RW*), **GDP**(*clear object type/ significance - interactivity of object of interest*)))
THEN **PP** = (*problems trying to execute action which does not exist*);

29 IF (NOT **GDP**(*clear action progress*))
OR (NOT **AMI**(**RI**(*semantics behind feedback received while carrying out action*), **KS**(*EM,OE,D,RW,T*), **GDP**(*clear during action effects*)))
THEN **PP** = (*difficulty assessing progress in action execution*);

T/A: recognise feedback

30 IF (NOT **AMI**(**RI**(*objects or self parts where action feedback will be represented*), **KS**(*EM,T,D,RW*), **GDP**(*declared feedback components*)))
THEN **PP** = (*difficulty determining where to check for feedback*);

31 IF (NOT **GDP**(*detectable self parts*))
OR (NOT **AMI**(**RI**(*location of feedback objects*), **KS**(*EM,D*), **GDP**(*locatable object/ areas of interest - feedback objects*)))
THEN **PP** = (*difficulty finding feedback not in immediate view*);

32 IF (NOT **GDP**(*declared action effect/ success*))
OR (NOT **AMI**(**RI**(*semantics behind action feedback*), **KS**(*EM,T,D,RW,OE*), **GDP**(*clear action effect*)))
OR (NOT **GDP**(*clear object state - permanently manipulated object*))
THEN **PP** = (*difficulty assessing success of action*);

T/A: inspect target

33 IF (NOT **GDP**(*accessible object - target*))
OR (NOT **GDP**(*distinguishable object/ object parts - parts of target object*))
OR (NOT **AMI**(**RI**(*identification information for target*), **KS**(*EM,D,RW*), **GDP**(*identifiable object/ object parts - parts of target object*)))
THEN **PP** = (*difficulty investigating target object*);

34 IF (NOT **AMI**(**RI**(*interactivity and relative importance of target*), **KS**(*EM,T,D,RW*), **GDP**(*clear object type/ significance - target*)))
OR (NOT **AMI**(**RI**(*purpose or function of target in environment*), **KS**(*EM,D,T,RW*), **GDP**(*clear object role - target*)))
OR (NOT **GDP**(*clear object state - target*))
THEN **PP** = (*difficulty obtaining required information about target object*);

T/A: evaluate with respect to intentions/goals

35 IF (NOT **AMI**(**RI**(*current task state*), **KS**(*T*), **GDP**(*clear task state*)))
OR (NOT **AMI**(**RI**(*intentions and task goals*), **KS**(*T*), **GDP**(*clear task/ task flow*)))
THEN **PP** = (*difficulty assessing whether goal or intention has been satisfied*);

36 IF (NOT **AMI(RI***(current task state)*, **KS***(T)*, **GDP***(clear task state)*))
OR (NOT **AMI(RI***(intentions and task goals)*, **KS***(T)*, **GDP***(clear task/ task flow)*))
THEN **PP** = *(difficulty assessing implications for goals and intentions)*;

37 IF (NOT **AMI(RI***(current task state)*, **KS***(T)*, **GDP***(clear task state)*))
OR (NOT **AMI(RI***(intentions and task goals)*, **KS***(T)*, **GDP***(clear task/ task flow)*))
OR (NOT **AMI(RI***(significance of system activity to overall goals and interaction and properties of system events)*, **KS***(EM,D,T)*, **GDP***(clear system activity significance)*))
OR (NOT **AMI(RI***(goals for system control)*, **KS***(EM,T,D)*, **GDP***(clear system control purpose)*))
OR (NOT **AMI(RI***(effects of system behaviour in environment)*, **KS***(EM,D,RW)*, **GDP***(declared causality and effects of behaviour)*))
THEN **PP** = *(difficulty assessing implications of system behaviour for goals and intentions)*;

38 IF (NOT **GDP***(reversible action effect)*)
THEN **PP** = *(difficulty overcoming errors in action execution)*;

E/N: general
39 IF (NOT **GDP***(relevant content, actions and events)*)
THEN **PP** = *(distraction from original task goals and intentions)*;

E/N: exploration no specific goal
40 IF (NOT **AMI(RI***(areas of interest or relevance to task)*, **KS***(EM,D,T)*, **GDP***(declared areas of interest)*))
THEN **PP** = *(difficulty deciding areas of interest)*;

E/N: scan environment
41 IF (NOT **GDP***(detectable self parts)*)
OR (NOT **AMI(RI***(self identification information)*, **KS***(EM,OE,RW)*, **GDP***(identifiable self parts)*))
THEN **PP** = *(difficulty distinguishing self from objects)*;

42 IF (NOT **GDP***(distinguishable object/ object parts - all objects in current percept)*)
OR (NOT **AMI(RI***(identification information for objects)*, **KS***(EM,D,RW)*, **GDP***(identifiable object - all objects in current percept)*))
THEN **PP** = *(difficulty determining what objects are in immediate vicinity)*;

43 IF (NOT **AMI(RI***(available environment components)*, **KS***(EM,D)*, **GDP***(discernible environment content set)*))
OR (NOT **GDP***(detectable self parts)*)
OR (NOT **GDP***(distinguishable object/ object parts - all objects in current percept)*)
THEN **PP** = *(problems distinguishing features as objects when no corresponding object)*;

44 IF (NOT **GDP***(clear current area)*)
THEN **PP** = *(difficulty determining whether currently within required area of interest)*;

45 IF (NOT **GDP***(distinguishable object/ object parts - target)*)
OR (NOT **AMI(RI***(identification information for target)*, **KS***(EM,D,RW)*, **GDP***(identifiable object - target)*))
THEN **PP** = *(difficulty determining whether target is in immediate vicinity)*;

46 IF (NOT **AMI(RI***(location of target)*, **KS***(EM,D)*, **GDP***(locatable object/ areas of interest - target)*))
THEN **PP** = *(problems with target not being in expected location)*;

47 **IF** (NOT **GDP**(*declared action effect/ success - navigation)*)
OR (NOT **AMI**(**RI**(*semantics behind feedback received after navigation),* **KS**(*EM,OE,RW,OE),* **GDP**(*clear action effect - navigation)*))
THEN **PP** = *(difficulty assessing success of previous navigation)*;

E/N: formulate plan

48 **IF** (NOT **AMI**(**RI**(*interactivity and relative importance of objects),* **KS**(*EM,T,D,RW),* **GDP**(*clear object type/ significance - all objects in current percept)*))
OR (NOT **AMI**(**RI**(*purpose or function of objects in environment),* **KS**(*EM,D,T,RW),* **GDP**(*clear object role - all objects in current percept)*))
THEN **PP** = *(difficulty detecting interesting objects to investigate)*;

49 **IF** (NOT **AMI**(**RI**(*areas of interest or relevance to task),* **KS**(*EM,D,T),* **GDP**(*declared areas of interest)*))
THEN **PP** = *(difficulty determining areas of interest to investigate)*;

50 **IF** (NOT **AMI**(**RI**(*significance of task action on target to overall goals),* **KS**(*T),* **GDP**(*clear task/ task flow)*))
OR (NOT **AMI**(**RI**(*task progress),* **KS**(*T),* **GDP**(*clear task state)*))
OR (NOT **AMI**(**RI**(*interactivity and relative importance of objects),* **KS**(*EM,T,D,RW),* **GDP**(*clear object type/ significance - all objects in current percept)*))
OR (NOT **AMI**(**RI**(*areas of interest or relevance to task),* **KS**(*EM,D,T),* **GDP**(*declared areas of interest)*))
THEN **PP** = *(difficulty deciding whether to carry out action on target, investigate interesting feature or explore further)*;

E/N: navigate

51 **IF** (NOT **AMI**(**RI**(*spatial structure of environment),* **KS**(*EM,D),* **GDP**(*discernible spatial structure)*))
OR (NOT **AMI**(**RI**(*location of areas of interest or target),* **KS**(*EM,D),* **GDP**(*locatable object/ areas of interest - destination)*))
THEN **PP** = *(difficulty locating the destination in the environment)*;

52 **IF** (NOT **GDP**(*clear current area)*)
THEN **PP** = *(difficulty determining self location in the environment)*;

53 **IF** (NOT **AMI**(**RI**(*best route to destination),* **KS**(*EM,D),* **GDP**(*identifiable optimal routes)*))
OR (NOT **AMI**(**RI**(*spatial structure of environment),* **KS**(*EM,D),* **GDP**(*discernible spatial structure)*))
THEN **PP** = *(difficulty determining most suitable route to destination)*;

54 **IF** (NOT **GDP**(*clear self position/state)*)
THEN **PP** = *(difficulty determining current self position and orientation in current percept)*;

55 **IF** (NOT **AMI**(**RI**(*procedure for navigation),* **KS**(*EM,OE,RW),* **GDP**(*declared action sequence - navigation)*))
OR (NOT **AMI**(**RI**(*available navigation pathways),* **KS**(*EM,D,RW),* **GDP**(*clear navigation pathways)*))
THEN **PP** = *(difficulty determining how to execute navigation)*;

56 **IF** (NOT **GDP**(*executable action - navigation)*)
THEN **PP** = *(difficulty executing navigation effectively and efficiently)*;

57 IF (NOT **GDP**(*clear action progress - navigation)*)
OR (NOT **AMI**(**RI**(*semantics behind feedback received while carrying out navigation),* **KS**(*EM,OE,RW),* **GDP**(*clear during action effects - navigation)*))
THEN **PP** = *(difficulty assessing progress in navigation)*;

58 IF (NOT **AMI**(**RI**(*unvisited and visited areas),* **KS**(*EM,T,D),* **GDP**(*clear visited areas)*))
OR (NOT **AMI**(**RI**(*spatial structure of environment),* **KS**(*EM,D),* **GDP**(*discernible spatial structure)*))
OR (NOT **GDP**(*environment enclosure)*)
THEN **PP** = *(difficulty suitably covering environment areas during exploration or searching)*;

E/N: intention to carry out exploratory/opportunistic actions
59 IF (NOT **AMI**(**RI**(*opportunities for action with objects of interest),* **KS**(*EM,D,T,RW),* **GDP**(*declared available action - all actions with objects of interest)*))
THEN **PP** = *(difficulty detecting what actions are available with the objects of interest)*;

60 IF (NOT **AMI**(**RI**(*semantics for actions & relevance/significance of actions to overall goals),* **KS**(*T,EM,RW),* **GDP**(*clear action purpose - all actions with objects of interest)*))
THEN **PP** = *(difficulty deciding which action to carry out)*;

S/I: general
61 IF (NOT **GDP**(*relevant content, actions and events)*)
OR (NOT **GDP**(*limited system control)*)
THEN **PP** = *(distraction from original task goals and intentions)*;

S/I: perceive and interpret event
62 IF (NOT **GDP**(*distinguishable behaviour)*)
OR (NOT **GDP**(*distinguishable object/ object parts - event objects)*)
THEN **PP** = *(difficulty distinguishing event)*;

63 IF (NOT **AMI**(**RI**(*identification information for event objects),* **KS**(*EM,D,RW),* **GDP**(*identifiable object/ object parts - event objects)*))
THEN **PP** = *(difficulty identifying event objects)*;

64 IF (NOT **AMI**(**RI**(*semantics for event),* **KS**(*EM,D,RW,T),* **GDP**(*declared causality and effects of behaviour)*))
THEN **PP** = *(difficulty interpreting the event)*;

S/I: acknowledge system control
65 IF (NOT **GDP**(*declared system control commencement/ termination - commencement)*)
THEN **PP** = *(difficulty realising commencement of system control)*;

66 IF (NOT **AMI**(**RI**(*goals for system control),* **KS**(*EM,T,D),* **GDP**(*clear system control purpose)*))
THEN **PP** = *(difficulty understanding goal of system in taking control of interaction)*;

S/I: monitor system control
67 IF (NOT **GDP**(*distinguishable behaviour)*)
OR (NOT **GDP**(*distinguishable object/ object parts - objects involved in system activity)*)
THEN **PP** = *(difficulty distinguishing system behaviour)*;

68 **IF** (NOT **AMI**(**RI***(semantics for system behaviour)*, **KS***(EM,D,RW,T)*, **GDP***(declared causality and effects of behaviour)*))
OR (NOT **AMI**(**RI***(identification information for involved objects)*, **KS***(EM,D,RW)*, **GDP***(identifiable object/ object parts - objects involved in system activity)*))
THEN **PP** = *(difficulty interpreting system behaviour)*;

S/I: intention to exercise user control

69 **IF** (NOT **AMI**(**RI***(actions available during system control)*, **KS***(EM,T,D)*, **GDP***(declared available actions during control)*))
THEN **PP** = *(difficulty determining whether/ what user control can be exercised)*;

70 **IF** (NOT **AMI**(**RI***(actions available during system control)*, **KS***(EM,T,D)*, **GDP***(declared available actions during control)*))
OR (NOT **AMI**(**RI***(goals for system control)*, **KS***(EM,T,D)*, **GDP***(clear system control purpose)*))
OR (NOT **AMI**(**RI***(significance of system behaviour to overall goals and interaction)*, **KS***(EM,D,T)*, **GDP***(clear system activity significance)*))
THEN **PP** = *(difficulty deciding whether to investigate exercising user control)*;

S/I: acknowledge end of system control

71 **IF** (NOT **GDP***(declared system control commencement/ termination - termination)*)
THEN **PP** = *(difficulty realising end of system control)*;

S/I: formulate reaction plan

72 **IF** (NOT **AMI**(**RI***(effects of system behaviour in environment)*, **KS***(EM,D,RW)*, **GDP***(declared causality and effects of behaviour)*))
OR (NOT **GDP***(clear object state - objects affected by system behaviour)*)
THEN **PP** = *(difficulty determining results of system activities)*;

73 **IF** (NOT **AMI**(**RI***(significance of system activity to overall goals and interaction)*, **KS***(EM,D,T)*, **GDP***(clear system activity significance)*))
OR (NOT **AMI**(**RI***(appropriate response to system activity)*, **KS***(EM,D,T,RW)*, **GDP***(appropriate response to system activity)*))
OR (NOT **AMI**(**RI***(goals for system control)*, **KS***(EM,T,D)*, **GDP***(clear system control purpose)*))
THEN **PP** = *(difficulty deciding appropriate response to system activity)*;

S/I: intention to carry out reactive action

74 **IF** (NOT **AMI**(**RI***(opportunities for action with event objects)*, **KS***(EM,D,T,RW)*, **GDP***(declared available action - actions with event objects)*))
(NOT **AMI**(**RI***(interactivity of event object)*, **KS***(EM,T,D,RW)*, **GDP***(clear object type/ significance - event objects)*))
THEN **PP** = *(difficulty detecting what actions are available on the event objects)*;

75 **IF** (NOT **AMI**(**RI***(semantics for actions)*, **KS***(EM,T,RW)*, **GDP***(clear action purpose - actions with event objects)*))
OR (NOT **AMI**(**RI***(appropriate action response to event)*, **KS***(EM,D,RW,T)*, **GDP***(appropriate response to system activity - reactive action)*))
THEN **PP** = *(difficulty deciding appropriate reactive action to event)*;

Appendix 5A: Pre-test questionnaire

Please complete and return to Kulwinder Kaur, A543, Centre for HCI Design. Thank-You.

Name:	
Sex: M/F	
Age (please):	

Contact details: (e.g. phone number, room number...)	

How much experience do you have in property inspection and evaluation?					
none		some		substantial	
number of years experience					
Give details					

How much experience do you have using direct-manipulation or Windows-style interfaces?					
none		some		substantial	
number of years experience					
Give details					

How much experience do you have in playing 3D video games, such as Doom?					
none		some		substantial	
number of years experience					
Give details					

How much experience do you have in using Virtual Reality applications?					
none		some		substantial	
number of years experience					
Give details					

How much experience do you have in using Superscape Virtual Reality applications?					
none		some		substantial	
number of years experience					
Give details					

Appendix 5B: Task notes

This document details the tasks you are to carry out in the virtual environment.

Try to complete tasks to the best of your ability. You do not have any specific time limits. Please complete tasks, as far as possible, in the order given.

Task scenario and overall goal

You are a salesperson who works for Rural Wales, a company that develops and sells business premises. You have been provided with a virtual environment representing the Newtown site. You may be provided with documents describing the site.

Your overall goal is to find out about the unit architecture and basic services of the Newtown site. You will need to use this information when approaching potential leaseholders.

Following this experiment, you will be questioned on the unit architecture and basic services of the premises represented in the virtual environment.

Task phase 1: familiarity with virtual environment

Spend 10 minutes familiarising yourself with the virtual environment. Investigate all 4 worlds.

Task phase 2: specific tasks

Complete the following tasks. There are 3 types of task as described.

Tasks type 1: finding and investigating objects

The following 2 objects can be found in the Empty world. Find and investigate these objects. You may be asked questions about the objects after the experiment.

window - there are many windows, all with similar characteristics, so investigate only 2 or 3 windows

water tank

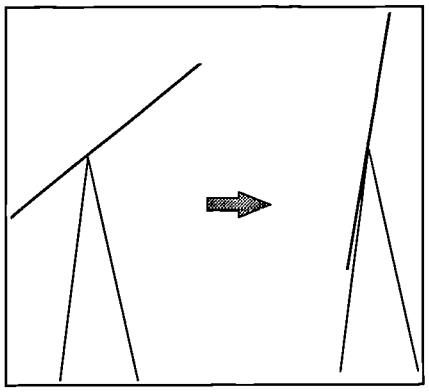
Tasks type 2: carrying out actions

Carry out the following 3 actions from within the Factory world. They may provide you with information useful to your overall goal.

Open the loading bay door

Switch all production area power on

Tilt the drawing board so that it is more directly facing you (see diagram)



Tasks type 3: analysis and problem solving

Carry out the following 3 general tasks. They will provide you with information useful to your overall goal.

For the main building:

Find out what areas of the building have a special factory floor covering.

Find out what general provisions are made for power sockets. You do not need information on the exact locations of individual sockets.

Compare the 3 toilets in the building (disabled, men's and women's). You are interested in what and how many facilities are in each toilet, and, comparing the spatial layout and size of the toilets and any other major differences.

End of Task.

Appendix 5C: Interaction notes

This document provides basic information you will need when interacting with the virtual environment.

Read carefully. The information in this document is summarised on the Interaction Look-up Card, for use during your interaction session.

Virtual Environment Application

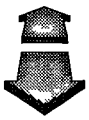
The virtual environment application comprises 4 separate worlds:
External world - representing an external view of the Newtown site and its surroundings
Empty world - representing a view inside one of the units within the site, the unit being shown as an empty complex
Factory world - representing an inside view of the same unit as a factory complex
Office world - representing an inside view of the same unit as an office complex

Interaction basics

You can switch between worlds by:

- pressing '[shift]G' to move to the next internal world (Empty, Factory, Office)
- pressing '[shift]H' to move to the External world

Use the joystick for navigation and orientation control.

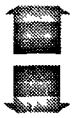


⇐ Move the joystick forward and back to move yourself forward and back in the virtual environment.

⇒ Move the joystick left and right to swivel left and right in the virtual environment.

⇐ With the left button depressed, move the joystick forward and back to tilt your viewing angle downwards and upwards, respectively.

⇒ With the right button depressed, move the joystick forward and back to heighten and lower yourself, respectively.



You may need to practice these controls, until confident you can control your position and orientation inside the virtual environment.

Additionally, within each world, there are 10 set positions that you can transport yourself to by pressing function keys 'F1' to 'F10'. You can return to your starting position in a world by pressing function key 'F12'. Note, this is a reset function which also returns all objects in the world to their original state.

Some objects in the virtual environment may be interacted with. Use the mouse for interacting with objects in a similar way to direct manipulation or Windows interfaces. Click on objects, with the left mouse button, to interact with them. Some actions involve mouse-drag operations where the left mouse button is depressed while the mouse dragged.

Appendix 5D: Application domain notes

This document describes the application domain for the virtual environment, giving considerations when investigating business premises and details of the Newtown business park.

Read carefully and familiarise yourself with the contents of this document prior to interaction. You may refer to the contents of this document during interaction.

Considerations when investigating business premises
When investigating premises for discussions with potential leaseholders, information should be sought about the basic architecture of the unit. This involves consideration of stories, rooms and exits available, areas and heights of rooms and overall layout. It is important to know the percentage of space that is usable, excluding such things as corridors, lift shafts, toilets, kitchen areas, etc. Characteristics of the shell of the building (e.g. doors, windows, roof...) should be investigated.

The location of the site is important for access to road, rail and air links and, access to local towns and shops. The premises may be restricted to use as an office or factory complex. The cost of occupying the premises should be investigated and this involves the rent, rates, any maintenance costs, costs in heating the building, etc.

Additionally, information should be sought about provisions for the following basic services and any other important features of the unit.
- natural and artificial lighting
- electrical power supplies and available room for electrical cabling
- gas supplies
- heating/air-conditioning facilities
- hot water supplies
- waste disposal facilities
- loading areas for goods
- kitchen and toilet facilities
- reception areas
- car parking

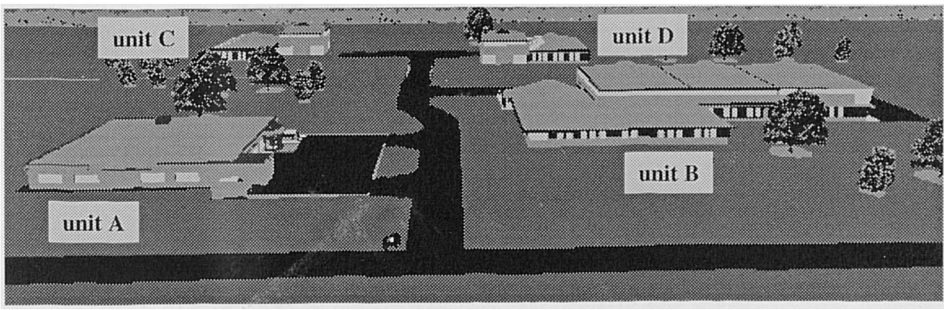
The Newtown business park
The Newtown site is a relatively small, rural site comprising 4 units situated near the town of Newtown. The largest unit is unit B, with the other units a similar size. Units are connected via a minor road system with one access, at the front of the site, to the main road system. There is a river dividing the site. Picture 1 shows the site.

<u>Unit A</u>
Unit A, shown in picture 2, is ready for leasing as either an office or factory complex.

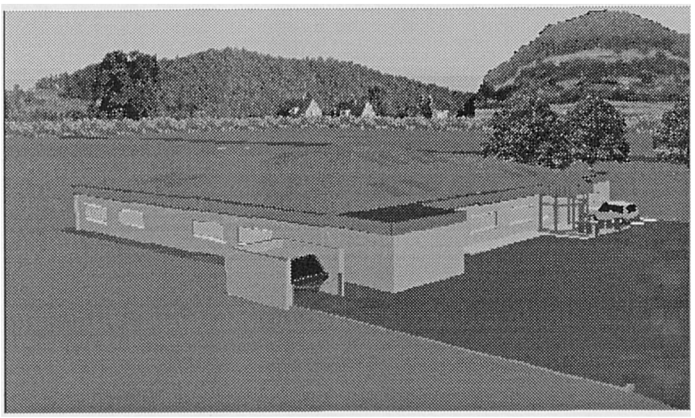
Unit A is a single story building comprising 10 areas: an entrance, hall, foyer/reception, main area, utility room, side room, kitchen and disabled, men's and w men's toilet. The unit has small carpark, a loading area and an attached skip. The

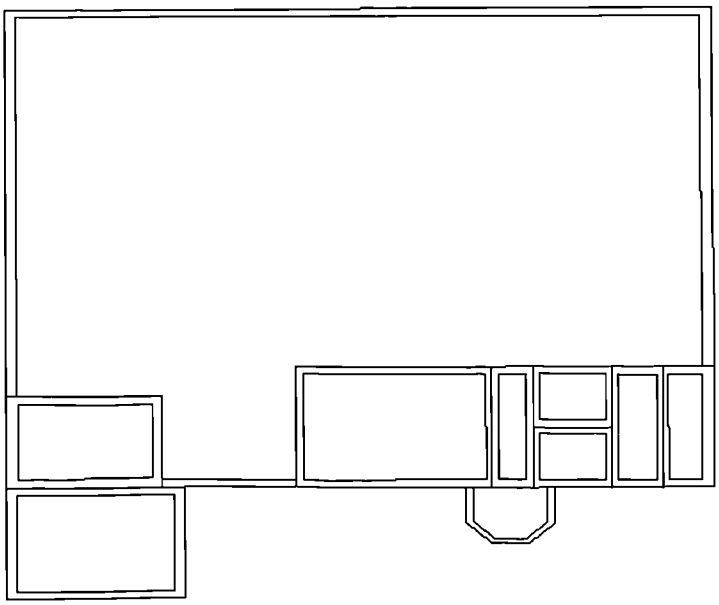
overall space occupied by unit A is 30 by 30 meters square. Percentage usable space calculated for the unit is 90%. The main area is 30 by 26 meters, and 3.5 meters high. The next largest room is the foyer which is about 11 by 4 meters, and 2.5 meters high. The kitchen and toilets are fitted. Other areas are empty apart from basic power supplies, heating and hot water supplies, and lighting. Basic aspects of the unit shell, such as windows, are fitted according to Rural Wales standards. Picture 3 shows the layout of unit A with only approximate divisions for individual areas.

Presently, information is not available about occupation costs for unit A.



Picture 1: Newtown Business Park


Picture 2: Unit A


Picture 3: Layout of Unit A

Appendix 5E: Post test

Test area 1: exploration

1. What actions are available in the Office world? (i.e. what objects respond when clicked with the mouse) Include actions common to all the internal worlds, as well as, actions specific only to the Office world.

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2. What objects are present in the Office world? Include objects common to all the internal worlds, as well as, objects specific only to the Office world.

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3. What information did you gather about heating and hot water supplies in the building?

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In the Empty world:

4. What object has a speech bubble attached to it?

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5. How is the appearance of this speech bubble triggered?

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6. What information does the speech bubble provide?

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Test area 2: unit architecture

7. Draw a diagram showing the layout (birds-eye view) of the External world? Include the extense of the External world and the positions of as many individual objects as you can. Use the A3 paper provided.

8. Draw a diagram showing the layout (birds-eye view) of the Empty world? Include the extense of the Empty world and the positions of as many individual objects as you can. Use the A3 paper provided.

Test area 3: task information
Tasks type 1: finding and investigating objects
In your investigations of the Empty world:

windows

9. What information did you gather about the windows? Provide as much information as you can.

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10. What interaction, if any, was available with the windows?

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water tank

11. Where did you find the water tank?

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12. What information did you gather about the water tank? Provide as much information as you can.

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13. What interaction, if any, was available with the water tank?

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Tasks type 2: carrying out actions

From carrying out specific actions within the Factory world:

Action: Open the loading bay door

14. What information did you gather about the loading bay?

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15. What was visible once the loading bay was open?

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Action: Switch all production area power on

16. What information did you gather about the production area power?

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17. What objects are involved in the production area power?

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18. How could production area power be switched on?

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19. How could you check whether production area power was switched on or off?

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Action: Tilt the drawing board so that it is more directly facing you

20. What parts of the drawing board are involved in this action and what is the relationship between them?

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21. How could the drawing board be tilted? What operations were involved?

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22. What illustration was on the drawing board? How could you make all parts of this illustration easier to view?

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Tasks type 3: analysis and problem solving

From analysing parts of the main building:

Task: Find out what areas of the building have a special factory floor covering.

23. What information did you gather about the special factory floor covering?

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24. How could you determine what areas of the building had a special factory floor covering?

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25. What areas of the building have a special factory floor covering? On your diagram of the layout the Empty world, show the exact extent of the special floor covering.

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Task: Find out what general provisions are made for power sockets.

26. What information did you gather about provisions for power sockets?

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27. What objects in the building did you use to carry out this task?

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Task: Compare the 3 toilets in the building (disabled, men's and women's).

28. How many lavatories are in each of the 3 toilets?

disabled:.....

men's:.....

women's:.....

29. How many wash basins are in each of the 3 toilets?

disabled:.....

men's:.....

women's:.....

30. Draw, in detail, the spatial layout (birds-eye view) of each of the 3 toilets, showing the position of as many individual objects as you can. Use the A3 paper provided.

31. Compare the overall size of the 3 toilets? Where there are differences in size, give estimated differences in percentage terms.

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End of post-test.

Appendix 5F: Retrospective questionnaire

Name:_____

Instructions:
Please answer all questions. For some questions a scale of 1 to 7 is given. Please circle the most appropriate number. You can add comments with your answers where you feel relevant.

****

1. How easy did you find the overall task?

Comments:

very difficult — very easy

2. How easy did you find the task of finding and investigating objects?
(windows and water tank)

Comments:

very difficult — very easy

3. How easy did you find the task of carrying out specific actions?
(opening loading bay door, switching production area power on, tilting drawing board)

Comments:

very difficult — very easy

4. How easy did you find the task of analysing aspects of the virtual environment?
(areas of the building with special factory floor covering, pr isions for power sockets, comparing toilets)

Comments:

very difficult — very ea y

5. How easy did you find it to explo e and familiarise yourself with the virtual environment?

Comments:

very difficult — very easy

6. Which of these automatic system behaviours did you experience (please tick) -

the drive through at the start of the External world ☐

the automatic opening doors for the main building in the External world ☐

the speech text attached to the man in the Empty world ☐

the phones ringing in the Factory and Office worlds ☐

How easy did you find it to interpret and react appropriately to the automatic system behaviours you experienced?

Comments:

very difficult — very easy

7. How easy did you find it to navigate in the virtual environment?

Comments:

very difficult — very easy

8. How easy did you find it to control your viewing angle in the virtual environment?

Comments:

very difficult — very easy

****

9. How useful were the general interaction notes and the interaction look-up card?

Comments:

not useful very useful

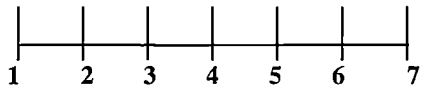
10. How useful did you find the application domain notes and the site and unit pictures?

Comments:

not useful very useful

11. If you have previous experience with 3D games or virtual reality applications, how useful did you find this experience?

Comments:



not useful very useful

****

12. What common or major problems did you face when interacting with the virtual environment?
Those related to your use of the interaction devices (joystick, mouse, keyboard):

Others:

13. What specific problems did you have when carrying out your task in the virtual environment?

14. What specific problems did you have exploring and familiarising yourself with the virtual environment?

15. What specific problems did you have interpreting and reacting appropriately to automatic system behaviours in the virtual environment?
(the drive through at the start of the External world, the automatic opening doors for the main building in the External world, the speech text attached to the man in the Empty world, the phones ringing in the Factory and Office worlds)

16. Were there any aspects of the virtual environment which you found particularly irritating although they did not cause major problems?

17. Were there any aspects of your interaction which you felt improved during your interaction session?

****

18. How good was the virtual environment in providing you with information about the following:

- information about the spatial layout of the environment, the available objects and their location

Comments:

very poor ... very good

- information about your current position and orientation in the environment

Comments:

very poor ... very good

- information about the objects in your vicinity, such as their identity, current state and their associated interactions

Comments:

very poor ... very good

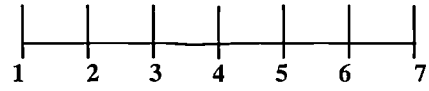
- information about the actions available with objects in your vicinity, such as the sequence of operations required to carry out the action and the resulting effect of the action

Comments:

very poor ... very good

- information about your progress whilst carrying out actions and the success of and effects of actions after they have been carried out

Comments:



very poor ... very good

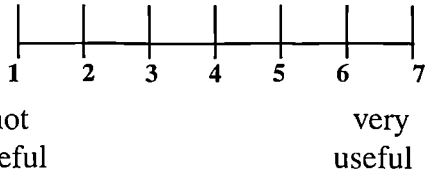
19. How useful to your interaction and task did you find the following features in the virtual environment:

- the ability to walk through objects in the worlds, such as walls and doors

Comments:

- the set positions attached to the function keys and the reset 'F12' function

Comments:

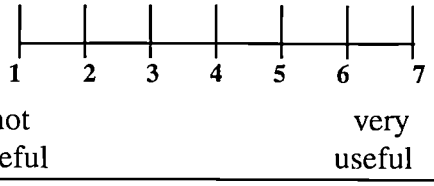


- the drive through at the start of the External world

Comments:

- the illustration on the drawing board and the view of the main building with the roof open in the External world (if you noticed them)

Comments:



20. Were there any parts of the virtual environment which you felt were irrelevant or distracting to your interaction and task? If so, which parts.

21. Was there any information missing in the virtual environment that you felt you needed to carry out the tasks and achieve your overall goal? If so, what.

22. What, if anything, would you like to change in the virtual environment.

****

23. How realistic did the virtual environment seem to you?

Comments:

not realistic — very realistic

24. How strong was your sense of presence, 'being there', in the virtual environment?

Very strong refers to a situation where you would feel as if you were inside the virtual environment and unaware of your surroundings whilst interacting with the virtual environment.

Very weak refers to a situation where you would have no feelings of presence inside the virtual environment and would feel as if you were only manipulating an image on a screen.

Comments:

very weak — very strong

25. How enjoyable did you find the session interacting with the virtual environment?

Comments:

not enjoyable — very enjoyable

26. How confident would you be about approaching potential leaseholders with the information you have gathered and with your answers for the post-test?

Comments:

not confident — very confident

27. Are there any other important points you would like to make?

****

Appendix 5G: Additional stages identified

The occurrence total and percentage for each of the 24 additional stages.

Additional stages	Total occurrence	% of all stages	Number of subjects
interpret navigation feedback	216	3.96	10 (all)
intention to execute command	104	1.91	9
scan and inspect an area	82	1.50	10
intention to approach target	78	1.43	10
consider location of target object	61	1.12	9
intention to open navigation access (e.g. door)	35	0.64	7
evaluate explorations carried out	33	0.61	9
deduce the sequence required for navigation	30	0.55	9
interpret feedback after an approach	17	0.31	7
deduce the interaction sequence after carrying out an action	12	0.22	5
scan and check the view angle or orientation of self	10	0.18	6
consider attributes of target object	8	0.15	5
evaluate all completed tasks	7	0.13	2
plan ahead for future tasks	6	0.11	4
consider content of environment	6	0.11	4
predict what a planned navigation will bring into view	5	0.09	4
plan how to take control back from the system	5	0.09	2
decide to give up on a task	4	0.07	3
intention to opportunistically carry out an action for another task	4	0.07	3
evaluate the environment state prior to an action execution	3	0.06	2
perceive the end of an event with a long duration	3	0.06	1
evaluate navigation method	3	0.06	3
predict what will be the outcome of an exploratory action	2	0.04	2
locate the current position in the world	1	0.02	1
TOTAL	**735**	**13.48**	

Appendix 5H: Application elements analysed and addressed

Environment element	Predicted problems for	Addressed in improved version
window	✓	✓
tank	✓	✓
open bay area	✓	✓
loading bay	✓	✓
mains	✓	✓
robots	✓	✓
utility switches	✓	✓
drawing board	✓	✓
floor	✓	✓
utility floor		
floor by bay		
foyer floor		
sockets	✓	✓
toilets	✓	✓
basins	✓	
loos	✓	
navigation	✓	✓
orientation	✓	✓
doors	✓	✓
exits	✓	✓
switch worlds	✓	✓
function keys		
joystick/ mouse		
ok button		
drive through	✓	✓
talking man	✓	✓
other man		
phone		
auto doors		
overall task		
spatial layout	✓	
external world		
foyer		
kitchen		
hall		
main room		
utility		
heater		
lights		
sink		
crates		
trunking	✓	✓
ceiling		
computer		
printer		
chairs		
clock		
dishwasher		
boiler		
posters		

boxes		
wine		
cupboards		
shadow objects		
office drawers		
foyer drawer		
wall		
fencing		
axis object		
sofa		
trees		
miscellaneous		
general objects/actions		✓

Appendix 5I: Unpredicted observed problems

Observed problem	Occurrences
Not know areas where can navigate	10
Not understand spatial structure of environment	7
Expected actions that are not available	6
Not know what objects are available in environment	6
Difficulties trying to interact with a dialogue box	3
Give-up trying to navigate to destination	3
Obstructed navigation pathways	3
Expected objects that are not available	3
Expected action sequence that is not implemented	2
Expected navigation style that is not implemented	2
Expected system behaviour that is not implemented	2
Give-up trying to open door	2
At an unsuitable viewing angle	2
Difficulties with the use of the domain plan	2
Bored with inherent object behaviour (robots)	1
Expected object collisions that are not implemented	1
Expected system control that is not implemented	1
Give-up trying to get required view angle	1
Difficulty effectively investigating an area	1
Want plan view of environment that is not available	1
Want reset view angle function that is not available	1
Confusion due to inconsistency in environment	1
Occurrence of nearby event not shown in view	1
Incorrect perception of object size/position	1
Unsure of plan guiding a system control	1
Expected further, related events from an original event	1
Unsure about the role of an object seen previously	1
Unsure why object is in its current state	1
Not want system control to occur	1
Deduced the wrong action sequence led to a desired effect	1

Appendix 5J: Assessment of problems from correspondence rules

KEY:

Problems observed for all predicted elements - *Always observed*
Problems observed for some, but not all, of the predicted elements - *Partially observed*
Problems predicted to occur but not observed at all - *Never observed*
Problems not predicted to occur but observed - *Additionally observed*
Problems not predicted to occur and not observed - *Not tested*

stage		problem	assessment
TA general	1	difficulty carrying out task as intended	not tested
TA establish goals	2	difficulty establishing clear goal	not tested
TA intention task action	3	difficulty establishing clear intention to act	not tested
TA consider objects	4	difficulty determining environment components involved in action	additionally observed
	5	difficulty determining whether target should be in immediate vicinity or require searching	never observed
	6	difficulty distinguishing target that should be in immediate vicinity	partially observed
	7	difficulty identifying target that should be in immediate vicinity	partially observed
TA approach/ orient	8	difficulty determining required object/self orientation for action	always observed
	9	difficulty determining current self position and orientation	always observed
	10	difficulty determining current object position and orientation	partially observed
	11	difficulty determining how to execute object approach	never observed
	12	difficulty executing object approach effectively and efficiently	partially observed
	13	difficulty assessing progress in object approach	not tested
	14	difficulty assessing success of object approach	not tested
	15	difficulty determining self parts involved in posture/orientation change	not tested
	16	difficulty identifying self parts involved in posture/orientation change	not tested
	17	difficulty determining how to execute self posture/orientation change	not tested
	18	difficulty executing self posture/orientation change efficiently and effectively	not tested
	19	difficulty assessing progress in self posture/orientation change	not tested
	20	difficulty determining where to check for self posture/orientation change feedback	not tested
	21	difficulty assessing success of self posture/orientation change	not tested
	22	difficulty determining whether further interaction required	not tested
	23	difficulty determining whether further interaction possible	partially observed
TA deduce sequence	24	difficulty determining parts involved	partially observed
	25	difficulty identifying parts involved	partially observed
	26	difficulty determining how to execute action	partially observed
TA execute	27	difficulty executing action efficiently and effectively	always observed
	28	problems trying to execute action which does not exist	always observed
	29	difficulty assessing progress in action execution	always observed
TA feedback	30	difficulty determining where to check for feedback	always observed
	31	difficulty finding feedback not in immediate view	never observed
	32	difficulty assessing success of action	always observed
TA inspect	33	difficulty investigating target object	partially observed
	34	difficulty obtaining required information about target object	partially observed
TA evaluate	35	difficulty assessing whether goal or intention has been satisfied	not tested
	36	difficulty assessing implications for goals and intentions	not tested
	37	difficulty assessing implications of system behaviour for goals and intentions	never observed
	38	difficulty overcoming errors in action execution	never observed
EN general	39	distraction from original task goals and intentions	not tested
EN explore	40	difficulty deciding areas of interest	additionally observed
EN scan	41	difficulty distinguishing self from objects	not tested
	42	difficulty determining what objects are in immediate vicinity	always observed
	43	problems distinguishing features as objects when no corresponding object	never observed
	44	difficulty determining whether currently within required area of interest	not tested
	45	difficulty determining whether target is in immediate vicinity	always observed
	46	problems with target not being in expected location	always observed

	47	difficulty assessing success of previous navigation	always observed
EN plan	48	difficulty detecting interesting objects to investigate	partially observed
	49	difficulty determining areas of interest to investigate	additionally observed
	50	difficulty deciding whether to carry out action on target, investigate interesting feature or explore further	never observed
EN navigate	51	difficulty locating the destination in the environment	always observed
	52	difficulty determining self location in the environment	additionally observed
	53	difficulty determining most suitable route to destination	always observed
	54	difficulty determining current self position and orientation in current percept	always observed
	55	difficulty determining how to execute navigation	always observed
	56	difficulty executing navigation effectively and efficiently	always observed
	57	difficulty assessing progress in navigation	always observed
	58	difficulty suitably covering environment areas during exploration or searching	always observed
EN intention explore action	59	difficulty detecting what actions are available with the objects of interest	additionally observed
	60	difficulty deciding which action to carry out	always observed
SI general	61	distraction from original task goals and intentions	never observed
SI event	62	difficulty distinguishing event	always observed
	63	difficulty identifying event objects	never observed
	64	difficulty interpreting the event	always observed
SI ack control	65	difficulty realising commencement of system control	always observed
	66	difficulty understanding goal of system in taking control of interaction	always observed
SI monitor	67	difficulty distinguishing system behaviour	not tested
	68	difficulty interpreting system behaviour	always observed
SI intention control action	69	difficulty determining whether/ what user control can be exercised	always observed
	70	difficulty deciding whether to investigate exercising user control	never observed
SI end control	71	difficulty realising end of system control	always observed
SI plan	72	difficulty determining results of system activities	never observed
	73	difficulty deciding appropriate response to system activity	partially observed
SI intention reactive action	74	difficulty detecting what actions are available on the event objects	always observed
	75	difficulty deciding appropriate reactive action to event	not tested

Appendix 5K: Related predicted problems

Pairs of predicted problems that were matched to the same observed problem at least 5 times (ordered).

	problem A		problem B
56	difficulty executing navigation effectively and efficiently	57	difficulty assessing progress in navigation
9	difficulty determining current self position and orientation	54	difficulty determining current self position and orientation in current percept
23	difficulty determining whether further interaction possible	28	problems trying to execute action which does not exist
33	difficulty investigating target object	45	difficulty determining whether target is in immediate vicinity
7	difficulty identifying target that should be in immediate vicinity	45	difficulty determining whether target is in immediate vicinity
24	difficulty determining parts involved	26	difficulty determining how to execute action
30	difficulty determining where to check for feedback	32	difficulty assessing success of action
42	difficulty determining what objects are in immediate vicinity	45	difficulty determining whether target is in immediate vicinity
12	difficulty executing object approach effectively and efficiently	33	difficulty investigating target object
7	difficulty identifying target that should be in immediate vicinity	33	difficulty investigating target object
23	difficulty determining whether further interaction possible	34	difficulty obtaining required information about target object
55	difficulty determining how to execute navigation	56	difficulty executing navigation effectively and efficiently

Appendix 5L: General predicted problems

Predicted problems that covered at least five incidents (on average) per environment element.

No	Problem	Incidents per element
51	difficulty locating the destination in the environment	20
56	difficulty executing navigation effectively and efficiently	14
57	difficulty assessing progress in navigation	13
58	difficulty suitably covering environment areas during exploration or searching	9
69	difficulty determining whether/ what user control can be exercised	7
65	difficulty realising commencement of system control	6
32	difficulty assessing success of action	5

Appendix 5M: Amendments to implement missing generic design properties

General objects and actions

GDP failures	Amendments
clear object type/ significance	standard cue - bright red and white for important actions - for information actions 'i' sign - for other actions outline objects
declared available action	*see above* – standard cue for actions

Windows and window information action

GDP failures	Amendments
declared available action	'I' sign for information, no activation from window objects
declared action components	clear boundary on 'I' sign
declared action sequence	*see above* – 'I' sign, simple click
clear action effect	no activation from walls under windows and during drag operations, information text says all windows follow the same standard

Water tank

GDP failures	Amendments
distinguishable object/object parts	add more detail and represent with colours contrasting with the background
identifiable object/object parts	make more representative – show as a container with water inside
clear object role	better representation (*see above*) and inactive status indicated by not including any action cues
clear object type/significance	*see above* – inactive status indicated
clear object position/orientation	NOT DONE (positioned in obscure part of unit – cannot change location)
accessible object	NOT DONE (positioned in obscure part of unit – cannot change location)

Loading bay door and action of opening loading bay door

GDP failures	Amendments
clear object role	no entry sign on close approach to area behind the bay door when it has been opened
clear object type/significance	no entry sign (*see above*) and outline whole active bay area
accessible object	limited close approach to the open bay area
declared available action	*see above* – outline active bay area
clear action purpose	separate information provision, using 'I' sign, from opening of door, using standard outlining of door
declared action components	*see above* – outline active area and separate information from door opening
declared action sequence	*see above* – outline active area

Mains, power switch and robot objects and **power information and switching power actions**

GDP failures	Amendments
distinguishable object/object parts	power switch made bigger and shown in more contrasting colours
identifiable object/object parts	information clearly available to provide identification
clear object role	information includes text detailing the link between the mains and power switch objects clear link with robots - start moving only when power on
clear object type/significance	'I' sign and outlining shows active objects
clear object state	larger and more prominent change in switch when on
accessible object	*see above* – switches made a little larger
declared available action	'I' signs and outline switches
clear action purpose	separate information provision, using 'I' sign, from switching on power, using switches themselves
declared action components	*see above* – 'I' signs and outlined switches
declared action sequence	*see above* – 'I' signs and outlined switches
declared feedback components	switch moves towards view when clicked and prominent change in state (*see above*), clear robot link - movement and sound starts when all switches are on
declared action effect/success	*see above* – clear change in state of switch and powering of robots
clear action effect	*see above* – clear on/off state of switch and running of robots

Drawing board and **actions to tilt board**

GDP failures	Amendments
distinguishable object/object parts	make handle larger, and represent in more luminous colours
identifiable object/object parts	information added to identify handle and plan on board
clear object role	information explains link between handle and board
clear object state	board is outlined as available for tilting when loose
accessible object	*see above* – handle larger
declared available action	*see above* – outlined board and handle and 'I' sign
clear action purpose	*see above* – 'I' sign gives detail of drawing board actions
clear self/object orientation for action	*see above* – information says where handle is on board
declared action sequence	*see above* – procedure explained in information, first handle only highlighted then board highlighted when loose
executable action	larger handle (*see above*) and simple click for handle not drag
reversible action effect	simple click to reverse handle
clear action progress	handle not dragged so no longer applicable
clear during action effects	*see above* - handle not dragged
declared feedback components	*see above* – board outlined when loose
declared action effect/success	clearer handle movement and outlining of board when loose (*see above*)
clear action effect	*see above* - handle movement and highlighting of board to show available for tilting

Special floor object and **floor information action**

GDP failures	Amendments
distinguishable object/ object parts	add detailed texture to special floor area
identifiable object/object parts	texture indicates nature of floor area and information available confirms identity
clear object role	*see above* – texture indicates special nature
clear object type/significance	information linked to 'I' sign and not floor itself
declared available action	*see above* – 'I' sign
declared action components	*see above* – 'I' sign
clear action effect	clear special floor boundary which flashes when information given

Power sockets and trunking objects and **socket information action**

GDP failures	Amendments
distinguishable object/ object parts	trunking and sockets shown in more luminous, contrasting colours and more detailed socket representations used
identifiable object/ object parts	sockets represented using more distinct 3 holes and information available to identify
clear object role	information text indicates link between sockets and trunking
clear object type/significance	'I' signs indicate available interactivity
declared available action	*see above* – 'I' signs
clear action purpose	*see above* – 'I' signs indicate provision of information
declared action components	*see above* – 'I' signs
declared action sequence	*see above* – 'I' signs
clear action effect	*see above* – 'I' signs indicate provision of information and text indicates link between sockets and trunking

Disabled, men's and women's toilets

GDP failures	Amendments
distinguishable object/ object parts	compartment walls represented in a different colour, edge textures used to separate walls
identifiable object/object parts	*see above* – compartment walls in specific colour and walls separated off from each other
clear object position/orientation	*see above* – positions of walls indicated by clearer edges between walls
accessible object	collision detection used on walls and limited close approach

Navigation and **orientation**

GDP failures	Amendments
clear navigation pathways	to match expectations collision detection on walls and limited close approach to walls 'no entry' signs to indicate unavailable areas such as exit doors
clear self position/state	limited view angle change to match human head adjustments permanent screen display of present height against range and present tilt against range
executable action	more suitable speed - slightly speeded up collision detection on walls and limited close approach to walls (*see above*)
clear action progress	*see above* – screen display of current viewpoint
clear during action effects	*see above* – make walls collidable and no extremes of view angle (e.g. being up-side down)
declared action effect/success	*see above* – screen indicator of current viewpoint
clear action effect	*see above* – screen indicator of current viewpoint

Doors and **exits** and **action of opening doors**

GDP failures	Amendments
identifiable object/object parts	label doors according to room behind them, have exit doors in different colour to internal doors
clear object role	label doors (*see above*) and for exit doors show no entry sign on close approach
clear object type/significance	highlight internal doors have no-entry sign for exit doors (*see above*)
accessible object	collision detection on walls and limited close approach, have doors facing and swinging in the appropriate direction
clear action purpose	*see above* – label doors
declared action components	show whole door is active by outlining it
clear self/object orientation for action	*see above* – have doors face and swing in expected direction
declared action sequence	*see above* – outline whole door
executable action	NOT DONE (mouse click registration issue could not be addressed)
clear action effect	*see above* – have doors swing in expected direction

Switch world command

GDP failures	Amendments
clear action progress	speech track to say now moving to ... world
clear action effect	message (*see above*), always transport to hall with door open to main area, and when switching back to external world remove the irrelevant dialogue box

Drive through system control

GDP failures	Amendments
declared system control commencement/ termination	speech track - announcing start of and end of drive through
clear system control purpose	speech track - saying drive around for familiarity and lasts for 2 minutes
declared available actions during control	speech track and message on screen - saying can use f10 to quit
limited system control	*see above* - give knowledge to user of how to end
clear system activity significance	*see above* – give knowledge about purpose

Speech bubble system event and **man object**

GDP failures	Amendments
distinguishable behaviour	speech bubble bigger and yellow
declared causality and effects of behaviour	normal speech bubble representation, from the mouth, and text says 'now you've come over I'd like to tell you that...'
identifiable object/object parts	man has different appearance from 2nd man and a badge with 'site manager' title
clear object type/significance	man beckons to indicate agent status
clear object role	*see above* - badge with title 'site manager'
clear object state	*see above* - clearer presence of speech bubble
clear position/orientation	less severe twisting of man to current viewpoint
accessible object	*see above* - less twisting of man

Appendix 5N: Scoring scheme for the post-study test

No.	Area	Question	How set score	Max	Score
1	Exploration	What actions are available in the Office world	20 actions - 0.5 each	10	
2		What objects are present in the Office world	43 objects - 0.25 each, up to 10	10	
3		What information ... heating and hot water supplies	1 for each point in information	3	
4		What object has a speech bubble attached to it	1 for man	1	
5		How is the appearance of this speech bubble triggered	1 for on approaching the man	1	
6		What information does the speech bubble provide	1 for size of main area	1	
				26	
7	Unit	Draw ... layout ... of the External world	12 objects - 1 each, up to 10; up to 5 for general layout	15	
8	Architecture	Draw ... layout ... of the Empty world	17 objects - 3/4 each, up to 10; up to 5 for general layout	15	
				30	
9	Task: objects	What information did you gather about the windows	1 for each point in information	2	
10		What... actions were available with the windows	1 for information provision	1	
11		Where did you find the water tank	1 for above kitchen	1	
12		What information ... about the water tank	1 for each descriptive point	2	
13		What... actions were available with the water tank	1 for no actions	1	
				7	
14	Task: actions	What information ... about the loading bay	1 for each point in information	3	
15		What was visible once the loading bay was open	1 for each descriptive point	2	
16		What information ... the production area power	1 for three-phase power installed	1	
17		What objects ... involved in production area power	1 for mains, 1 for switches in utility room	2	
18		How could production area power be switched on	1 for using switches in utility room	1	
19		How ... check ... production area power ... on or off	1 for red lights turn on or robots move	1	
20		What parts ... involved ... what is the relationship ...	1 each board and handle, handle loosens board	3	
21		How could the drawing board be tilted	1 for turn handle; 1 for then tilt board	2	
22		What illustration ... How ... made easier to view?	1 for plan of building; 1 for move ruler out of way	2	
				17	
23	Task: analysis	What information ... special factory floor covering	1 for each point in information	2	
24		How ... determine what areas ... special ... covering	1 for find areas giving information	1	
25		What areas ... covering... show the exact extent ...	1 for general main area; 2 for specific part of main area	2	
26		What information ... provisions for power sockets	1 for each point in information or descriptive point	3	
27		What objects ... did you use to carry out this task	1 for investigating rooms; 2 for using information box	2	
28		How many lavatories are in each of the 3 toilets	1 for correct number for each toilet	3	
29		How many wash basins are in each of the 3 toilets	1 for correct number for each toilet	3	
30		Draw... layout ... toilets... What ....differences ...	18 objects - 0.5 each; up to 1 for general layout each toilet	12	
31		Compare the overall size of the 3 toilets	1 each for correct order of size; 1 each extra for within 5% accuracy	4	
				32	
			TOTAL SCORE	**112**	
			PERCENTAGE SCORE	**100**	

Appendix 5O: Average ratings in the retrospective questionnaire

Significant differences (where $p<0.05$) are highlighted.

	1-7 scale questions	Control	GDP
1	easy overall task	4.3	4.2
2	easy object tasks	4.5	4.3
3	easy action tasks	2.1	4.8
4	easy analysis tasks	3.8	4.7
5	easy exploration	4.6	3.9
6	easy system behaviour	3	4.2
	experienced drive through (% of subjects)	90%	90%
	experienced automatic doors	40%	20%
	experienced man speech	40%	100%
	experienced phones	90%	90%
7	easy navigation	5.3	4.3
8	easy orientation	4.8	3.6
9	useful interaction notes	4.7	5.3
11	useful 3D games experience	4.2	4.9
18	good spatial information	4.5	4.4
	good own position information	4.3	3.3
	good objects information	2.9	4.7
	good actions information	2.1	3.8
	good action feedback information	3.3	3.5
19	useful non collision detection	3.5	N/A
	useful action highlighting	N/A	5.6
	useful orientation figure	N/A	1.8
	useful set positions + reset	3.3	3.6
	useful drive through	2.1	2.7
	useful illustration on board + open roof	3.3	1.9
23	realistic	4.3	3.7
24	sense of presence	4.9	3.2
25	enjoyable interaction session	5.3	4.9
26	confidence in approaching leaseholders	2.3	2.7

NOTE: *Although there was a large difference in the average ratings for Q19, for the useful of the illustration on the board, it was not reliably statistically significant because only three subjects in the control group and six in the amended group responded to this question.*

Appendix 5P: List of rules in the problem prediction expert system

```
CRYSTAL MASTER RULE
      + IF problem predictor

problem predictor
        IF        DO: Init. Variables
      +  AND information known
      +  AND predict problems
      +  AND give summary

information known
        IF   predict on general information
      +  AND ask user class
      +  AND ask elements supported

      + OR   ask on individual elements

ask user class
        IF   user knows about USER TASK
         AND       DO: Fail

        OR   user knows about SCOPE OF ENVIRONMENT
         AND       DO: Fail

        OR   user knows about SPATIAL STRUCTURE of environment
         AND       DO: Fail

        OR   user knows about SELF & VIEWPOINT in environment
         AND       DO: Fail

        OR   user knows about OBJECTS in environment
      +  AND set object knowledge
         AND       DO: Fail

        OR   user knows about SYSTEM BEHAVIOUR in environment
      +  AND set system behaviour knowledge
         AND       DO: Fail

        OR   user knows about ACTIONS & FEEDBACK in environment
         AND       DO: Fail

        OR        DO: Succeed

 set object knowledge
        IF        DO: Assign Variable
                  UKidentity_object:=1

set system behaviour knowledge
        IF        DO: Assign Variable
                  UKcontrol_purpose:=1
         AND      DO: Assign Variable
                  UKcontrol_actions:=1
         AND      DO: Assign Variable
                  UKcause_effect_behaviour:=1
         AND      DO: Assign Variable
                  UKsignificance_behaviour:=1
         AND      DO: Assign Variable
                  UKresponse_behaviour:=1
```

```
ask elements supported
        IF   VE provides information about USER TASK
         AND      DO: Fail

        OR   VE provides information about SCOPE of ENV
         AND      DO: Fail

        OR   VE provides information about SPATIAL STRUCTURE
         AND      DO: Fail

        OR   VE provides information about SELF & VIEWPOINT
         AND      DO: Fail

        OR   VE provides information about OBJECTS
       +  AND set object GDPs
   AND      DO: Fail

        OR   VE provides information about SYSTEM BEHAVIOUR
       +  AND set system behaviour GDPs
         AND      DO: Fail

        OR   VE provides information about ACTIONS & FEEDBACK
         AND      DO: Fail

        OR        DO: Succeed

set object GDPs
        IF        DO: Assign Variable
                  GDPdistinguish_object:=1
         AND      DO: Assign Variable
                  GDPidentity_object:=1
         AND      DO: Assign Variable
                  GDPobject_state:=1

set system behaviour GDPs
        IF        DO: Assign Variable
                  GDPcontrol_start_end:=1
         AND      DO: Assign Variable
                  GDPcontrol_purpose:=1
         AND      DO: Assign Variable
                  GDPcontrol_actions:=1
         AND      DO: Assign Variable
                  GDPlimited_control:=1
         AND      DO: Assign Variable
                  GDPdistinguish_behaviour:=1
         AND      DO: Assign Variable
                  GDPcause_effect_behaviour:=1
         AND      DO: Assign Variable
                  GDPsignificance_behaviour:=1
         AND      DO: Assign Variable
                  GDPresponse_behaviour:=1

ask on individual elements
       W IF       DO: Menu Question  elementtype$
  What type of element is involved?

                  {task & environment }
                  {spatial structure  }
                  {self & viewpoint   }
                  {navigation         }
                  {an object          }
                  {an action          }
                  {a system event     }
                  {a system control   }
  +  AND get information by element type
```

```
get information by element type
        IF      DO: Test Expression
                elementtype$="a system control"
      +  AND get information on a system control

        W OR        DO: Display Form
                    Problem prediction rules for:
                        [elementtype$       ]

                    have not yet been implemented.

get information on a system control
      + IF   get GDPs supported
      +  AND get user knowledge present

get GDPs supported
        IF   VE declares start & end of this control
         AND      DO: Assign Variable
                  GDPcontrol_start_end:=1
         AND      DO: Fail

        OR   VE makes purpose of control clear
         AND      DO: Assign Variable
                  GDPcontrol_purpose:=1
         AND      DO: Fail

        OR   VE declares actions available during the control
         AND      DO: Assign Variable
                  GDPcontrol_actions:=1
         AND      DO: Fail

        OR   VE limits amount of system control
         AND      DO: Assign Variable
                  GDPlimited_control:=1
         AND      DO: Fail

        OR   VE makes system behaviour distinguishable
         AND      DO: Assign Variable
                  GDPdistinguish_behaviour:=1
         AND      DO: Fail

        OR   VE declares cause and effect of system behaviour
         AND      DO: Assign Variable
                  GDPcause_effect_behaviour:=1
  AND      DO: Fail

        OR   VE makes significance of system activity clear
         AND      DO: Assign Variable
                  GDPsignificance_behaviour:=1
         AND      DO: Fail

        OR   VE makes appropriate response to activity clear
         AND      DO: Assign Variable
                  GDPresponse_behaviour:=1
         AND      DO: Fail

        OR   VE makes system activity objects distinguishable
         AND      DO: Assign Variable
                  GDPdistinguish_object:=1
         AND      DO: Fail

        OR   VE makes identity of system activity objects clear
         AND      DO: Assign Variable
                  GDPidentity_object:=1
         AND      DO: Fail

        OR   VE makes state of system activity objects clear
         AND      DO: Assign Variable
                  GDPobject_state:=1
         AND      DO: Fail

        OR       DO: Succeed
```

```
get user knowledge present
        IF   user knows purpose of system control
         AND      DO: Assign Variable
                  UKcontrol_purpose:=1
         AND      DO: Fail

        OR   user knows actions available during control
         AND      DO: Assign Variable
                  UKcontrol_actions:=1
         AND      DO: Fail

        OR   user knows cause and effect of system behaviour
         AND      DO: Assign Variable
                  UKcause_effect_behaviour:=1
         AND      DO: Fail

        OR   user knows significance of system activity
         AND      DO: Assign Variable
                  UKsignificance_behaviour:=1
         AND      DO: Fail

        OR   user knows appropriate response to system activity
         AND      DO: Assign Variable
                  UKresponse_behaviour:=1
         AND      DO: Fail

        OR   user knows identity of objects in system activity
         AND      DO: Assign Variable
                  UKidentity_object:=1
         AND      DO: Fail

        OR        DO: Succeed


predict problems
      + IF   system control relevant
      +  AND predict problems for system control

system control relevant
        IF   predict on general information

        OR        DO: Test Expression
                  elementtype$="a system control"

predict problems for system control
      + IF   acknowledge start of system control
      +  AND monitor system control
      +  AND intention to exercise user control stage
      +  AND acknowledge end of system control stage

acknowledge start of system control
      + IF   difficulty realising start of system control
      W  AND      DO: Display Form
                  WPOS: 2,15,10,50
                   Usability problem predicted:

                    difficulty realising start of system control

                   during stage: acknowledge start of system control

                   caused by: poor cueing of commencement of control
                  COL : SURR       White on Blue
                  COL : 0,0        White on Blue

         AND      DO: Assign Variable
                  problem_count:=problem_count+1
         AND      DO: Fail
```

```
    + OR   difficulty understanding goal of system control
    W  AND      DO: Display Form
                WPOS: 2,15,10,50
                 Usability problem predicted:

                 difficulty understanding goal of system control

                 during stage: acknowledge start of system control

                 caused by: poor information about goal of control
                     or: poor user knowledge about goal
               COL : SURR       White on Blue
               COL : 0,0        White on Blue

      AND       DO: Assign Variable
                problem_count:=problem_count+1
      AND       DO: Fail

     OR         DO: Succeed


difficulty realising start of system control
     IF         DO: Test Expression
                GDPcontrol_start_end<>1


difficulty understanding goal of system control
     IF         DO: Test Expression
                UKcontrol_purpose<>1
      AND       DO: Test Expression
                GDPcontrol_purpose<>1


monitor system control
     + IF   difficulty distinguishing system behaviour
     W  AND      DO: Display Form
                WPOS: 2,15,10,50
                 Usability problem predicted:

                 difficulty distinguishing system behaviour

                 during stage: monitor system control

                 caused by: poorly represented system behaviour
                     or: poorly represented objects in behaviour
               COL : SURR       White on Blue
               COL : 0,0        White on Blue

      AND       DO: Assign Variable
                problem_count:=problem_count+1
      AND       DO: Fail

     + OR   difficulty interpreting system behaviour
     W  AND      DO: Display Form
                WPOS: 2,15,10,50
                 Usability problem predicted:

                 difficulty interpreting system behaviour

                 during stage: monitor system control

                 caused by: poor information on behaviour meaning
                     or: poor user knowledge about behaviour
                     or: poor information on object identities
                     or: poor user knowledge about objects
               COL : SURR       White on Blue
               COL : 0,0        White on Blue

      AND       DO: Assign Variable
                problem_count:=problem_count+1
      AND       DO: Fail
  OR        DO: Succeed
```

```
difficulty distinguishing system behaviour
        IF      DO: Test Expression
                GDPdistinguish_behaviour<>1

        OR      DO: Test Expression
                GDPdistinguish_object<>1

difficulty interpreting system behaviour
        IF      DO: Test Expression
                UKcause_effect_behaviour<>1
         AND    DO: Test Expression
                GDPcause_effect_behaviour<>1

        OR      DO: Test Expression
                UKidentity_object<>1
         AND    DO: Test Expression
                GDPidentity_object<>1

intention to exercise user control stage
+ IF  difficulty determining whether/ what user control
      W AND     DO: Display Form
                WPOS: 2,15,10,50
                Usability problem predicted:

                difficulty determining whether/ what user control
                can be exercised

                during stage: intention to exercise user control

                caused by: poor information on control actions
                    or: poor user knowledge about actions
               COL : SURR      White on Blue
               COL : 0,0       White on Blue

         AND    DO: Assign Variable
                problem_count:=problem_count+1
         AND    DO: Fail

        OR      DO: Succeed


difficulty determining whether/ what user control
        IF      DO: Test Expression
                UKcontrol_actions<>1
         AND    DO: Test Expression
    GDPcontrol_actions<>1

acknowledge end of system control stage
      + IF  difficulty realising end of system control
      W AND     DO: Display Form
                WPOS: 2,15,10,50
                Usability problem predicted:

                difficulty realising end of system control

                during stage: acknowledge end of system control

                caused by: poor cueing of termination of control
               COL : SURR      White on Blue
               COL : 0,0       White on Blue

         AND    DO: Assign Variable
                problem_count:=problem_count+1
         AND    DO: Fail

        OR      DO: Succeed

difficulty realising end of system control
        IF      DO: Test Expression
                GDPcontrol_start_end<>1
```

```
give summary
        IF          DO: Test Expression
                    problem_count=0
        W  AND          DO: Display Form
                    No usability problems were predicted.

        W OR            DO: Display Form
                    [prob]  problem(s) were predicted.
                       problem_count
```

Appendix 5Q: Refinements to stages of interaction

Existing stage	Assessment	Comments	Changes
TA establish goals	*Validated*		
TA intention task action	*Validated*		Extend this stage to include *consider objects* behaviour
TA consider objects	*Remove*	Results show for most intended actions, little consideration of objects involved. Can be incorporated into related *intention task action*, as optional behaviour.	Remove this stage.
TA approach/orient	*Validated*		Extend this stage to include *intention to approach target.*
TA deduce sequence	*Validated*		
TA execute	*Validated*		
TA feedback	*Validated*		
TA inspect	*Validated*		
TA evaluate	*Validated*		
EN explore	*Validated*		
EN scan	*Validated*		Extend this stage to include *scan and inspect an area.*
EN plan	*Validated*		Extend this stage to include *consider location of target object.*
EN navigate	*Validated*		Extend this stage to include *interpret navigation feedback.*
EN intention explore action	*Retain*	Important action type, e.g. undertaken by 80% subjects. Reasons not occurred, e.g. too little exploration time.	
SI event	*Retain*	Important behaviour when event occurs. Reasons not occurred, e.g. limited stimuli (3 events).	
SI ack. control	*Retain*	Important behaviour, e.g. undertaken by 80% subjects. Not expected to be common (one occurrence required for control start), but maintains temporal sequence of interaction during control.	
SI monitor	*Validated*		
SI intention control action	*Validated*		
SI end control	*Retain*	Reasons not occurred, e.g. subjects quit drive before end. Not expected to be common (one occurrence required for control end), but maintains temporal sequence of interaction during control.	
SI plan	*Retain*	Reasons not occurred, e.g. limited system behaviour. Important behaviour because separately captures decision making about responses to system behaviour and data showed many different possible responses.	
SI intention reactive action	*Retain*	Reasons not occurred, e.g. limited stimuli (1 relevant event). Not expected to be common (in environments with limited system prompts and events), but separates distinct action type.	

Additional behaviour	Assessment	Comments	Changes
interpret navigation feedback	*include*	Important for more general situations when learning the navigation technique or encountering problems in navigation. Optional in navigation so incorporate with related stage.	
intention to execute command	*include*	Important new action type representing actions for moving through the environments, e.g. to set positions or opening doors. Does not incorporate well with existing stages, and theory distinguishes different action types, so include as new stage.	Include this behaviour as a new stage, *intention move action*.
scan and inspect an area	*include*	Important behaviour for whole area inspection rather than specific objects, especially for analysis tasks. Optional style of scanning so incorporate with related stage.	
intention to approach target	*include*	Decisions to approach targets generally applicable and should be incorporated with main approach activity.	
consider location of target object	*include*	Important behaviour when user lacks knowledge about object locations and should be incorporated with main navigation planning activity.	

Appendix 5R: Refinements to flow of interaction in models

Task action mode

Predicted Flow	Assessment	Comment	Changes
'est goals' - 'intention task action'	*validated*		
'intention task action' - 'consider objects'	*remove*	'consider objects' stage removed	replace with (observed) flow from 'intention task action' - 'approach/orient'
'consider objects' - 'approach/orient'	*remove*	'consider objects' stage removed	see above
'approach/orient' - 'deduce seq'	*retain*	maintains a basic path	
'deduce seq' - 'execute'	*validated*		
'execute' - 'feedback'	*validated*		
'feedback' - 'evaluate'	*retain*	may not have been found because of concurrent navigation behaviour and frequent re-trying of actions, maintains a basic path	
'approach/orient' - 'inspect'	*validated*		
'inspect' - 'evaluate'	*retain*	may not have been found because of frequent re-trying of approaches, maintains a basic path	
'evaluate' - 'intention task action'	*remove*	cyclic path - shown to be less important, simplify model by merging flows and having only one flow back to start of model	remove flow and retain only one flow back to start of model
'evaluate' -'est goals'	*retain*	may not have been found because of concurrent navigation behaviour and frequent backtracking, maintains a cyclic path	
'consider objects' - EN 'scan'	*remove*	'consider objects' stage removed	replace with (observed) transfer from 'intention task action' - see later
Other common observed flow	**Assessment**	**Comment**	**Changes**
'intention task action' - 'approach/orient'	*include*	'consider objects' stage removed	see above changes
'intention task action' - 'execute'	*include*	common jump forward for skilled users	add to jump path to 'execute' stage
'approach/orient' - 'execute'	*include*	common jump forward for skilled users	add to jump path to 'execute' stage
'feedback' - 'execute'	*include*	common backtrack for re-trying actions	add to back path to 'execute' stage
'inspect' - 'approach/orient'	*include*	common backtrack for re-trying approaches	add as backtrack flow
'inspect' - 'execute'	*include*	common cross for inspection followed by manipulation	add as link flow
'evaluate' - 'execute'	*include*	common backtrack for re-trying actions	add to back path to 'execute' stage
'intention task action' - EN 'navigate'	*include*	common (predicted) transfer for target searches, transfers also observed from 'est goals' but simplify by including one transfer for target searches	add as transfer path for target searches
'evaluate' - EN 'navigate'	*include*	common transfer for return to default navigation after action and covers return to navigation for new move action type, transfers also observed from 'feedback' but simplify by including one transfer for return to navigation	add as transfer path at action end

Explore navigate mode

Predicted Flow	Assessment	Comment	Changes
'explore' - 'scan'	*remove*	expected to be uncommon generally	replace with (observed) flow from 'explore' to 'navigate'
'scan' - 'plan'	*retain*	may not have been found because of highly frequent navigation maintains a basic path	
'plan' - 'navigate'	*validated*		
'navigate' - 'scan'	*validated*		
'plan' - 'intention explore action'	*retain*	may not have been found because of highly frequent navigation and very few exploratory actions maintains a path to exploratory actions	
'plan' - TA 'approach/orient'	*retain*	may not have been found because of highly frequent navigation and few target searches maintains a transfer for targets found	
'intention explore action' - TA 'approach/orient'	*validated*		
Other common observed flow	**Assessment**	**Comment**	**Changes**
'explore' - 'navigate'	*include*	major internal flow following 'explore' stage	add as flow following 'explore' stage
'scan' - 'navigate'	*include*	common jump for situated navigation	add as jump to 'navigate'
'navigate' - 'plan'	*include*	common jump for situated navigation	add as jump to 'plan'
'plan' - 'intention move action'	*include*	incoming flow for new stage, plan stage most appropriate link since involves decision making about navigation and exploration	add as incoming flow to new stage
'intention move action' - TA 'approach/orient'	*include*	outgoing flow for new stage, approach/orient stage most appropriate transfer since matches links used for other intended actions	add as transfer from new stage

System initiative mode

Predicted Flow	Assessment	Comment	Changes
'ack control' - 'monitor'	*validated*		
'monitor' - 'intention control action'	*validated*		
'monitor' - 'end control'	*retain*	may not have been found because 'end control' less common maintains basic path through model	
'end control' - 'plan'	*retain*	may not have been found because 'plan' less common maintains basic path through model	
'event' - 'plan'	*retain*	may not have been found because 'plan' less common maintains basic path through model	
'plan' -'intention reactive action'	*retain*	may not have been found because 'intention reactive action' less common maintains basic path through model	
'intention control action' - TA 'approach/orient'	*retain*	may not have been found because navigation mainly used as the control action and because of jumps forward, direct to 'execute' maintains a transfer for control actions	
'plan' - TA 'evaluate'	*remove*	transfers for evaluating effect of system behaviour on task not found to be common	replace with more general transfer to beginning of task action mode
'plan' - EN 'intention explore action'	*remove*	transfers for exploratory actions related to system behaviour not found to be common	replace with more general transfer to beginning of explore navigate mode
'intention reactive action' - TA 'approach/orient'	*retain*	may not have been found because of jumps forward direct to 'execute' maintains a transfer for reactive actions	
Other common observed flow	**Assessment**	**Comment**	**Changes**
'ack control' - 'intention control action'	*include*	common jump for exiting control when realise started	add as jump to 'intention control action'
'intention control action' - EN 'navigate'	*include*	common transfer for regaining control through navigation, as a control action	add as transfer to 'navigate'
'end control' - TA 'est goals'	*include*	transfer for focus on task, after system behaviour transfer jumped forward, skipping SI 'plan' stage, but include as link from 'plan'	add as general transfer to 'est goals' from 'plan'
'end control' - EN 'explore'	*include*	transfer for focus on explorations, after system behaviour, transfers also observed to EN 'plan' and 'navigate' but simplify by including one transfer path, transfer jumped forward, skipping SI 'plan' stage, but include as link from 'plan'	add as general transfer to 'explore' from 'plan'

Appendix 5S: Refinements to problem prediction rules

stage		Predicted problem	*assessment*	comments	changes
TA general	1	difficulty carrying out task as intended	*not tested*		
TA establish goals	2	difficulty establishing clear goal	*not tested*		
TA intention task action	3	difficulty establishing clear intention to act	*not tested*		
TA consider objects	4	difficulty determining environment components involved in action	*validated*		take out env. components condition (see later)
	5	difficulty determining whether target should be in immediate vicinity or require searching	*remove*	covered by locating target problems, e.g. 45	remove rule
	6	difficulty distinguishing target that should be in immediate vicinity	*remove*	continues from removed rule 5 and related to removed rule 7	remove rule
	7	difficulty identifying target that should be in immediate vicinity	*remove*	occurred with 45 and can be covered by 45 since this often next stage, also occurred with 33	remove rule
TA approach/ orient	8	difficulty determining required object/self orientation for action	*validated*		
	9	difficulty determining current self position and orientation	*retain*	occurred with 54, but relates to different stage and mode	
	10	difficulty determining current object position and orientation	*validated*		
	11	difficulty determining how to execute object approach	*retain*	issue in problem matching - matched such difficulties to general rules on navigation for simplicity	
	12	difficulty executing object approach effectively and efficiently	*retain*	occurred with 33, but 33 on specific path for inspections only	
	13	difficulty assessing progress in object approach	*not tested*		
	14	difficulty assessing success of object approach	*not tested*		
	15	difficulty determining self parts involved in posture/orientation change	*remove*	not tested but mimics action problem 24 which has been shown to be unnecessary	remove rule
	16	difficulty identifying self parts involved in posture/orientation change	*remove*	not tested but mimics action problem 25 which has been shown to be unnecessary	remove rule
	17	difficulty determining how to execute self posture/orientation change	*not tested*		
	18	difficulty executing self posture/orientation change efficiently and effectively	*not tested*		
	19	difficulty assessing progress in self posture/orientation change	*not tested*		
	20	difficulty determining where to check for self posture/orientation change feedback	*remove*	not tested but mimics action problem 30 which has been shown to be unnecessary	remove rule
	21	difficulty assessing success of self posture/orientation change	*remove*	shown to be duplicated by 9, from analysis of orientation rules required in navigate stage (see later)	remove rule
	22	difficulty determining whether further interaction required	*not tested*		
	23	difficulty determining whether further interaction possible	*retain*	occurred with 28, but relates to different stage occurred with 34 and 34 removed	

TA deduce seq	24	difficulty determining parts involved	*remove*	occurred with 26, in same stage, and can be covered by 26 since this is part of difficulty in 26	remove rule
	25	difficulty identifying parts involved	*remove*	continues from removed rule 24	remove rule
	26	difficulty determining how to execute action	*retain*	occurred with 24 and 24 removed	
TA execute	27	difficulty executing action efficiently and effectively	*validated*		
	28	problems trying to execute action which does not exist	*retain*	occurred with 23, but relates to different stage and is an important effect of difficulty in 23	
	29	difficulty assessing progress in action execution	*validated*		
TA feedback	30	difficulty determining where to check for feedback	*remove*	occurred with 32, in same stage, and can be covered by 32 since this is part of difficulty in 32	remove rule
	31	difficulty finding feedback not in immediate view	*retain*	only predicted for one element so not strong test	
	32	difficulty assessing success of action	*retain (split)*	occurred with 30 and 30 removed	split into more specfic problems (see later)
TA inspect	33	difficulty investigating target object	*retain*	occurred with 45, but relates to different behaviour at different stage, occurred with 12, but this relates specifically to inspections and 12 to general approaches, occurred with 7 and 7 removed	include condition for object role (see 34)
	34	difficulty obtaining required information about target object	*remove*	occurred with 23 and partially covered by 23 in immediately previous behaviour, uncovered areas (object role) can be included in 33	remove rule
TA evaluate	35	difficulty assessing whether goal or intention has been satisfied	*not tested*		
	36	difficulty assessing implications for goals and intentions	*not tested*		
	37	difficulty assessing implications of system behaviour for goals and intentions	*remove*	linked to general assessment of system behaviour on task being uncommon	remove rule
	38	difficulty overcoming errors in action execution	*retain*	undoing actions not required in this VE but may be important in others	
EN general	39	distraction from original task goals and intentions	*not tested*		
EN explore	40	difficulty deciding areas of interest	*not tested*		
EN scan	41	difficulty distinguishing self from objects	*not tested*		
	42	difficulty determining what objects are in immediate vicinity	*retain*	occurred with 45, but this relates to general exploration and 45 to target searches	
	43	problems distinguishing features as objects when no corresponding object	*remove*	minor issue and can be covered by 42	remove rule
	44	difficulty determining whether currently within required area of interest	*not tested*		
	45	difficulty determining whether target is in immediate vicinity	*retain*	occurred with 33, but relates to different behaviour at different stage, occurred with 7 and 7 removed, occurred with 45, but this relates to target searches and 45 to general exploration	
	46	problems with target not being in expected location	*validated*		

	47	difficulty assessing success of previous navigation	*remove*	this rule more for discrete orientation changes rather than continuous movement - since orientation now to be handled separately by additional rules, 47 not needed	remove rule
EN plan	48	difficulty detecting interesting objects to investigate	*retain*	non-goal directed exploration problem, while study was quite task directed	
	49	difficulty determining areas of interest to investigate	*validated*		
	50	difficulty deciding whether to carry out action on target, investigate interesting feature or explore further	*remove*	decision-making difficulties not generally found to exist	remove rule
EN navigate	51	difficulty locating the destination in the environment	*validated*		
	52	difficulty determining self location in the environment	*not tested*		
	53	difficulty determining most suitable route to destination	*retain*	predicted for only one element and found once, so not strong test	
	54	difficulty determining current self position and orientation in current percept	*retain*	occurred with 9, but relates to different stage and mode	
	55	difficulty determining how to execute navigation	*retain*	occurred with 56, but useful to maintain sequence/execution distinction	
	56	difficulty executing navigation effectively and efficiently	*retain*	occurred with 57, but useful to maintain action/feedback distinction occurred with 55, but useful to maintain sequence/execution distinction	take out navigation pathways condition (see later)
	57	difficulty assessing progress in navigation	*retain*	occurred with 56, but useful to maintain action/feedback distinction	reword for not under-standing navigation path taken (see later)
	58	difficulty suitably covering environment areas during exploration or searching	*validated*		
EN intention explore action	59	difficulty detecting what actions are available with the objects of interest	*not tested*		
	60	difficulty deciding which action to carry out	*retain*	predicted for only one element and found once, so not strong test	
SI general	61	distraction from original task goals and intentions	*retain*	little system behaviour and most at start when task not ongoing, so not strong test	
SI event	62	difficulty distinguishing event	*validated*		
	63	difficulty identifying event objects	*remove*	less important & can be covered by 64 by including condition for identifying objects	remove rule
	64	difficulty interpreting the event	*validated*		include condition for object identity (see 63)
SI ack control	65	difficulty realising commencement of system control	*validated*		
	66	difficulty understanding goal of system in taking control of interaction	*validated*		
SI monitor	67	difficulty distinguishing system behaviour	*not tested*		
	68	difficulty interpreting system behaviour	*retain*	predicted for only one element and found once, so not strong test	
SI intention control action	69	difficulty determining whether/ what user control can be exercised	*validated*		

	70	difficulty deciding whether to investigate exercising user control	*remove*	decision-making difficulties not generally found to exist	remove rule
SI end control	71	difficulty realising end of system control	*validated*		
SI plan	72	difficulty determining results of system activities	*remove*	re-interpretation of behaviour which is already handled in 64 or 68	remove rule
	73	difficulty deciding appropriate response to system activity	*retain*	predicted for two elements and found once, so not strong test	
SI intention reactive action	74	difficulty detecting what actions are available on the event objects	*retain*	predicted for only one element and found once, so not strong test	
	75	difficulty deciding appropriate reactive action to event	*not tested*		

Uncovered problems areas	*Assessment*	**Comments**	**Additions**
New stage: *Intention move action*	*include*	new stage needing rules - similar to other intention action stages	2 new rules similar to 59, 60 and 74, 75
EN plan extended to include *consider location of target object*	*include (move elsewhere)*	rules for this covered but in *navigate* stage not *plan* stage	move rules relating to spatial planning (51, 52, 53, 58) to *plan*
where can navigate	*include*	new rule for difficulties determining available navigation pathways, existing rule 56 take out navigation pathways condition	new rule for EN plan stage
spatial structure	*include*	new rule for difficulties understanding the spatial structure of the environment or current area	new rule for EN plan stage
objects in world	*include*	new rule for difficulty determining environment components available, existing rule 4 take out environment components condition	new rule for TA intention task action stage
obstructed pathways	*include*	new rule for difficulties finding unobstructed pathways for navigation	new rule for EN plan stage
unsuitable angle	*include*	new rule for difficulties maintaining suitable viewing angle	new rule for EN navigate and TA approach/orient stages

	Overly general predicted problems	*Assessment*	**Comments**	**Additions**
56	difficulty executing navigation effectively and efficiently	*include*	- can extend to cover orientation changes separately (but there is already rule 54 for the posture/ orientation state) and - separate remaining problems of: 1. moving at suitable speeds 2. moving in particular direction (equivalent to current problem) 3. reaching destinations (severe form of inability to move in direction desired, above) 4. avoiding obstacles (already done)	- separate rules for orientation (see approach stage rules 17, 18, 19) - new rule for problems moving at suitable speed
57	difficulty assessing progress in navigation	*include (alter description)*	- can extend to cover orientation changes separately, - specific cases of not understanding the current view are handled better by existing rules 41, 42, 52 and - can reword this rule to describe remaining issues of not understanding the navigation path just taken	- separate rules for orientation (see above) - reword 57 for changed emphasis
65	difficulty realising commencement of system control	*include*	can include additional rule to cover specific cases of thinking have control when have not	new rule for problems thinking have user control

32	difficulty assessing success of action	*include*	can separate into specific problems: 1. inadequate/missing feedback, 2. not understanding feedback, 3. thinking action has had an effect it has not 4. expecting action to have some other effect (but expectation problems generally not included)	- detail 32 further for specific feedback problems, 1 - 3

Descriptions for changed and new rules

Changed rules

Rule 4:

IF (NOT **AMI**(**RI***(action components)*, **KS***(T,EM,RW)*, **GDP***(clear task components)*))
THEN **PP** = *(difficulty determining environment components involved in action)*;

Rule 33:

IF (NOT **GDP***(accessible object - target)*)
OR (NOT **GDP***(distinguishable object/ object parts - parts of target object)*)
OR (NOT **AMI**(**RI***(identification information for target)*, **KS***(EM,D,RW)*, **GDP***(identifiable object/ object parts - parts of target object)*))
OR (NOT **AMI**(**RI***(purpose or function of target in environment)*, **KS***(EM,D,T,RW)*, **GDP***(clear object role - target)*))
THEN **PP** = *(difficulty investigating target object)*;

Rule 56:

IF (NOT **AMI**(**RI***(procedure for navigation)*, **KS***(EM,OE,RW)*, **GDP***(declared action sequence - navigation)*))
THEN **PP** = *(difficulty determining how to execute navigation)*;

Rule 57:

IF (NOT **GDP***(clear action progress - navigation)*)
OR (NOT **AMI**(**RI***(semantics behind feedback received while carrying out navigation)*, **KS***(EM,OE,RW)*, **GDP***(clear during action effects - navigation)*))
THEN **PP** = *(difficulty assessing navigation path taken)*;

Rule 64:

IF (NOT **AMI**(**RI***(semantics for event)*, **KS***(EM,D,RW,T)*, **GDP***(declared causality and effects of behaviour)*))
OR (NOT **AMI**(**RI***(identification information for event objects)*, **KS***(EM,D,RW)*, **GDP***(identifiable object/ object parts - event objects)*))
THEN **PP** = *(difficulty interpreting the event)*;

New rules

IF (NOT **AMI**(**RI***(available environment components)*, **KS***(EM,D)*, **GDP***(discernible environment content set)*))
THEN **PP** = *(difficulty determining environment components available)*;

IF (NOT **GDP***(clear self position/state)*)
OR (NOT **AMI**(**RI***(possible changes to self posture and orientation)*, **KS***(EM,D,T,RW)*, **GDP***(declared available action - all self posture and orientation actions)*))
THEN **PP** = *(difficulties maintaining a suitable viewing angle)*;

IF (NOT **AMI**(**RI***(available navigation pathways)*, **KS***(EM,D,RW)*, **GDP***(clear navigation pathways)*))
THEN **PP** = *(difficulties determining available navigation pathways)*;

IF (NOT **GDP***(UNOBSTRUCTED NAVIGATION PATHWAYS)*)
THEN **PP** = *(difficulties finding unobstructed pathways for navigation)*;

IF (NOT **AMI**(**RI**(*spatial structure of environment or current area*), **KS**(*EM,D*), **GDP**(*discernible spatial structure*)))
THEN **PP** = (*difficulties understanding the spatial structure of the environment or current area*);

IF (NOT **GDP**(*APPROPRIATE NAVIGATION SPEEDS*))
THEN **PP** = (*difficulty moving at suitable speeds*);

IF (NOT **AMI**(**RI**(*opportunities for movement action*), **KS**(*EM,D,T,RW*), **GDP**(*declared available action - all movement actions*)))
THEN **PP** = (*difficulty detecting what movement actions are available*);

IF (NOT **AMI**(**RI**(*resulting effect of movement actions*), **KS**(*T,EM,RW*), **GDP**(*clear action purpose - all movement*)))
THEN **PP** = (*difficulty deciding appropriate movement action to carry out*);

IF (NOT **GDP**(*declared system control commencement/ termination - commencement*))
OR (NOT **AMI**(**RI**(*actions 'not' available during system control*), **KS**(*EM,T,D*), **GDP**(*declared available actions during control*)))
THEN **PP** = (*problems believing have user control when do not*);

Identical conditions as in existing rules 17, 18 and 19 in TA approach/orient stage

- *difficulty determining how to execute self posture/orientation change*
- *difficulty executing self posture/orientation change efficiently and effectively*
- *difficulty assessing progress in self posture/orientation change*

IF (NOT **GDP**(*declared action effect/ success*))
OR (NOT **GDP**(*clear object state - permanently manipulated object*))
THEN **PP** = (*problems with inadequate or missing feedback*);

IF (NOT **AMI**(**RI**(*semantics behind action feedback*), **KS**(*EM,T,D,RW,OE*), **GDP**(*clear action effect*)))
THEN **PP** = (*difficulty interpreting the feedback*);

IF (NOT **GDP**(*declared action effect/ success*))
OR (NOT **AMI**(**RI**(*semantics behind action feedback*), **KS**(*EM,T,D,RW,OE*), **GDP**(*clear action effect*)))
OR (NOT **GDP**(*clear object state - permanently manipulated object*))
THEN **PP** = (*problems believing an action has had an effect it has not*);

Appendix 5T: Refinements to generic design properties

Category	Generic Design Property	*Assessment*	Comments	Changes
User task	**action support for task**	*not tested*		
	relevant content, actions and system behaviour	*not tested*		
	clear task/ task flow	*not tested*		
	clear task components	*not tested*		
	clear task state	*not tested*		
Overall Environment	**discernible environment content set**	*not tested*		
	discernible repertoire of opportunities for action	*validated*	not implemented caused problem mains 1	
	declared areas of interest	*not tested*		
Environment spatial layout	**clear current area**	*not tested*		
	environment enclosure	*retain*	implemented not common problem area in this VE	
	discernible spatial structure	*validated*	not implemented e.g. caused problem board 2	
	locatable object/ areas of interest	*validated*	not implemented e.g. caused problem board 2	
	identifiable optimal routes	*not tested*		
	clear visited areas	*retain*	not implemented not common problem area in this VE	
Objects	**distinguishable object/ object parts**	*validated*	implemented e.g. reduced problem floor 1	
	identifiable object/ object parts	*validated*	implemented e.g. reduced problem exits 3	
	clear object role	*validated*	implemented e.g. reduced problem doors 6	
	clear object type/ significance	*validated*	implemented e.g. reduced problem exits 1	
	clear object state	*validated*	implemented e.g. reduced problem utility switch 1	
	clear object position/ orientation	*validated*	implemented e.g. caused problem toilets 2	
	accessible object	*validated*	implemented e.g. reduced problem doors 1	
Self object	**detectable self parts**	*not tested*		
	identifiable self parts	*not tested*		
	clear self parts role	*remove*	only appears in removed rules	remove GDP
	clear navigation pathways	*retain*	implemented no predicted problem for, but related to unpredicted problem - where can navigate	
	clear self position/state	*retain*		
System behaviour	**declared system control commencement/ termination**	*validated*	implemented e.g. reduced problem drive 2	
	clear system control purpose	*validated*	implemented e.g. caused problem drive 6	
	declared available actions during control	*validated*	implemented e.g. reduced problem drive 1	
	limited system control	*retain*	implemented limited implementation and not common problem area in this VE	
	distinguishable behaviour	*validated*	implemented e.g. caused problem man info 4	
	declared causality and effects of behaviour	*validated*	implemented e.g. caused problem man info 5	

	clear system activity significance	*validated*	implemented e.g. caused problem man info 2	
	appropriate response to system activity	*retain*	not implemented not common problem area since lacking for only 1 event	
Actions	**declared available action**	*validated*	implemented e.g. reduced problem loading bay 6	
	clear action purpose	*validated*	implemented e.g. reduced problem doors 6	
	declared action components	*remove*	only appears in removed rules and is covered by declared action sequence	remove GDP
	clear self/object orientation for action	*validated*	implemented e.g. reduced problem board 7	
	declared action sequence	*validated*	implemented e.g. reduced problem loading bay 6	
	executable action	*validated*	implemented e.g. reduced problem navigation 4	
	reversible action effect	*retain*	implemented not common problem area in this VE	
Action feedback	**clear action progress**	*validated*	implemented e.g. reduced problem switch worlds 1	
	clear during action effects	*validated*	implemented e.g. reduced problem navigation 2	
	declared feedback components	*remove*	only appears in removed rules, covered by declared action effect/ success	remove GDP
	declared action effect/ success	*validated*	implemented e.g. reduced problem utility switch 1	
	clear action effect	*validated*	implemented e.g. reduced problem doors 7	
Category	**GDPs for rule changes**	***Assessment***	**Comments**	**Changes**
self object	unobstructed navigation pathways	*include*	GDP for ensuring that navigation pathways are not obstructed	add GDP
self object	appropriate navigation speeds	*include*	GDP for ensuring the speed of navigation is suitable for the navigation tasks involved	add GDP

Appendix 6A: Design guidelines

Guidelines are given by components of the environment model (i.e. the GDP categories), beginning with the user task.

The user task or goal set is what the user intends to carry out or achieve through interaction in the VE.

GDP: **action support for task**

Design guideline: The actions and objects that the user needs to complete her task or achieve goals should be available in the VE. The user should be able to carry out actions in the order defined by her task.

Motivation: Essential as basis for enabling the user to fulfil goals and tasks.

Context of use: More applicable to VEs with a well-defined user task that can be divided into a set of actions to be carried out. For more open user goals, actions and objects of interest to the user should be included.

Examples: In a training application, the set of actions making up a specific training task are available in the VE to be practised. In an educational VE, the goal to learn about a subject area is aided by including objects and actions important within the subject area.

GDP: **relevant content, actions and system behaviour**

Design guideline: Elements included in the VE should be relevant to the user's task or goals. Elements can be objects, actions and automatic system behaviour. For automatic system behaviour, this should be timed appropriately with regard to the user's task.

Motivation: Avoids the user wasting time exploring when there is little relevance to her overall goals, or being distracted from her task.

Context of use: More important for VEs with a well-defined task the user needs to complete.

Examples: In an application to learn about the solar system, elements such as other stars and Earth satellites are not included to focus attention on the Sun and nine planets. In a tourism application, a guided tour of a place is presented only after the user has been given basic information about the area.

GDP: **clear task/ task flow**

Design guideline: The user's task in interacting with the VE should be clearly defined. The steps required to perform the task should be clear. The link between task actions and the user's overall goals should be clear.

Motivation: Provides essential information about the user's task, when this information is not otherwise available.

Context of use: Less applicable where the user already has knowledge about the task or is provided with this information, for example through de-briefing or documentation. Less applicable for open-ended user goals, such as exploration.

Examples: In a training application for engine assembly, the user is provided with details of an assembly task and the sequence of operations required to successfully complete the assembly. In a route learning application, the user is prompted to proceed via the most efficient route to the next destination.

GDP: **clear task components**

Design guideline: The environment components required for the user's task actions should be made clear. The actual components involved in the task should meet any user expectations.

Motivation: Necessary to enable the user to begin a task by making clear to her what objects have to be found in the VE and acted upon.

Context of use: Less applicable where the user already has knowledge about the task or is provided with this information, for example through de-briefing or documentation. Less applicable for open-ended user goals, such as exploration, where there are only areas of interest rather than specific objects.

Examples: In a training application for engine assembly, the user is provided with details of components required for the next part of the assembly. In a teleoperation application to remotely maintain satellites, the user is actively given details of which objects in the VE to manipulate in order to control remote robots for a repair task.

GDP: **clear task state**

Design guideline: Information should be readily available about the state of the user task, such as completed goals and unfulfilled goals. Changes to the task state should be clearly presented.

Motivation: Provides necessary up-to-date information about the user's task when the user is not likely to be able to recall this information.

Context of use: Important where the user has a structurally complex task to carry out and remembering all required information about the state of the ongoing task will be too demanding.

Examples: In a training application for submarine familiarisation, the VE permanently shows the number of pieces of equipment that have been correctly identified by the user so far. In a tourism application, information is provided about places that have been visited and remarks made by the user.

General information about the entire environment and not just the part that is currently available.

GDP: **discernible environment content set**

Design guideline: The general contents of the VE should be made clear to the user on her early encounters with the VE. The general contents should meet any user expectations.

Motivation: Necessary for the user to understand the general scope of the VE and gain overall information about what objects can be found, thereby aiding exploration of the VE.

Context of use: Particularly important for exploratory applications. Less applicable where the user has information about the VE contents, for example as in the case of VEs closely modelling a domain well known to the user.

Examples: In a marketing application of a business park, the user is initially taken on a drive through the whole park. In a supermarket application, the various shelf areas have easily visible labels suspended from the ceiling.

GDP: **discernible repertoire of opportunities for action**

Design guideline: The general opportunities for action within the VE should be made clear to the user on her early encounters with the VE. General limitations on action should also be made clear. The general opportunities for action should meet any user expectations.

Motivation: Necessary for the user to understand the general scope of the VE and gain overall information about what actions can be carried out, thereby aiding exploration of the VE.

Context of use: Particularly important for exploratory applications. Less applicable where the user has information about actions available in the VE, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In a training application for submarine familiarisation, a message is first presented to the user informing them that they can click on pieces of equipment to find out their identity. In a kitchen design/evaluation application, the user is provided with an animated demonstration of the main changes that can be made to a kitchen design.

GDP: **declared areas of interest**

Design guideline: The areas of interest in the VE, with respect to the user's goals, should be made clear to the user on her early encounters with the VE. Significant parts of the VE should attract attention and other areas should be less conspicuous.

Motivation: Aids the user in exploring the VE by directing attention towards important areas and drawing attention away from unimportant parts.

Context of use: Particularly important for exploratory applications. Less applicable where the user has information about areas of interest in the VE, for example as in the case of VEs closely modelling a domain well known to the user.

Examples: In an application to learn about the solar system, the user is first provided with an overview of the solar system with the sun and nine planets as the only prominent objects in view. In a marketing application of a business park, the user is initially taken on a drive around the available premises, which are shown in greater detail than those unavailable and include a 'To Let' sign.

Spatial information about the environment layout and object locations.

GDP: **clear current area**

Design guideline: The part of the VE which is currently being observed, in relation to the whole VE, should be made clear to the user.

Motivation: Necessary for the user to be able to locate her current position in the VE, thereby allowing for planning of navigation and search operations.

Context of use: More consideration needs to be given in the case of large, complex VEs, and where the user has little spatial knowledge of the VE.

Examples: In an architectural walkthrough of a large building, a plan of the building is provided including an indication of the user's current position. In a supermarket application, labels for each shelf area help indicate the user's current position.

GDP: **environment enclosure**

Design guideline: The VE should have a clear spatial boundary and the user should not be allowed to take position outside the scope of the VE.

Motivation: Necessary for the user to be able to understand the spatial scope of the VE, thereby aiding exploration. Prevents the user from exploring outside the scope of the VE.

Context of use: For more open VEs, such as outdoor simulations including background landscapes, an appropriate boundary needs to be defined whilst, at the same time, maintaining an adequate representation of an extended background.

Examples: In a marketing application of a business park, the spatial boundary is the park itself which is represented in detail. Background landscapes of the park are shown as blurry, distant images. In an architectural walkthrough inside part of a building, exit doors and doors to unavailable parts of the building cannot be opened and are shown with 'Exit' and 'No Entry' signs.

GDP: **discernible spatial structure**

Design guideline: The spatial layout of the VE should be made clear to the user. The layout should match any user expectations.

Motivation: Necessary for the user to be able to plan general exploration, and navigation and search operations.

Context of use: More consideration needs to be given in the case of large, complex VEs, and where the user has little spatial knowledge of the VE. For applications not closely modelling the spatial structure of a domain, the VE should be designed to have a simple, systematic layout.

Examples: In an architectural walkthrough of a large building, a plan of the building is provided. In a small exhibition application, stalls are organised in a systematic layout with a central reception area, linked to and visible from all of the stall aisles.

GDP: **locatable object/ areas of interest**

Design guideline: Important objects and areas of interest to the user should be easily locatable. Locations of objects should meet any user expectations.

Motivation: Aids the user in quickly finding components of interest.

Context of use: More consideration needs to be given in the case of large, complex VEs, and where the user has little spatial knowledge of the VE. For applications not closely modelling the layout of a domain, the VE should be designed so that components of interest are positioned in immediately obvious areas of the VE, alongside related components, or, are positioned in commonly visited areas.

Examples: In an application to learn about the solar system, the user is provided with a menu of the major objects. An object can be selected and will be highlighted on an overall plan to aid location of the object. In a supermarket application, labels for each shelf area help the user locate individual items, which are grouped according to the type of product they are.

GDP: **identifiable optimal routes**

Design guideline: The best (easiest, shortest) routes to possible destinations in the VE should be clear to the user. The user should be able to assess and compare the time required to traverse along different routes and the kind of obstacles to pass along the way.

Motivation: Aids the user in quickly reaching intended destinations in the VE.

Context of use: More consideration needs to be given in the case of large, complex VEs, and where the user has little spatial knowledge of the VE. For applications not closely modelling the layout of a domain, the VE should be designed to have a simple and systematically organised set of paths and routes.

Examples: In an architectural walkthrough of a large building, a plan (to scale) of the building is provided including available doors to rooms, corridors linking rooms, lifts to other floors, and private office areas indicated. In a library application, sections of the library are numbered and positioned in order. With sections being linked to a small set of aisles, the user can easily find the quickest route between two areas of the library.

GDP: **clear visited areas**

Design guideline: The areas in the VE that the user has visited and the areas that remain to be visited should be clear to her.

Motivation: Necessary for the user to be able to efficiently explore the VE, covering all areas and not revisiting areas unnecessarily.

Context of use: More consideration needs to be given in the case of large, complex VEs, and where the user has little spatial knowledge of the VE. For applications not closely modelling the layout of a domain, the VE should be designed to have a set of coherent areas, clearly distinct from one another.

Examples: In an architectural walkthrough of a large building, a plan of rooms in the building is provided with visited rooms shown in a different colour. In an exhibition application, stalls are organised by type into a set of aisles with a central reception area. Each aisle has a label and unique colour scheme, and aisles and stalls that the user has visited are shown with greyed colours and blurred textures.

The self object represents the user and user actions. The viewpoint is the angle from which the environment is viewed. The self object is fixed to the viewpoint. User actions are linked directly to input devices e.g. mouse click, gesture with glove, push of joystick.

GDP: **detectable self parts**
Design guideline: The parts of the self, representing the user, should be easy to locate from any orientation and should be clearly distinguished from the rest of the environment.
Motivation: Necessary to enable the user to quickly find the different parts of the self object for carrying out actions with self parts and checking the state of the self
Context of use: Particularly important for more complex self objects, where actions are carried out with parts of the self object, and when the state of the self object is changeable. Not applicable where there is no represented self object.
Examples: In an architectural walkthrough, the self is shown permanently in the bottom of the screen as a stick-man in red, a colour used little in the environment. In an engine assembly application, the user manipulates objects and the self is made up of two hands, which appear on the bottom of the screen in the default (and initial) viewing angle, which is straight ahead.

GDP: **identifiable self parts**
Design guideline: The identity of the parts of the self should be made clear to the user and should match any user expectations.
Motivation: Necessary to enable the user to identify parts of the self for carrying out actions and checking the state of the self.
Context of use: Particularly important for more complex self objects, where actions are carried out with parts of the self object, and when the state of the self object is changeable. Not applicable where there is no represented self object.
Examples: In an engine assembly application, the self is made up of two hands shown with extended arms and in a realistic skin colour. They are linked to the viewpoint at a natural angle (i.e. waist level and straight ahead). In a driving simulation application, the self includes a realistically represented car interior with major components, such as a steering wheel.

GDP: **clear navigation pathways**
Design guideline: The valid paths through the environment that the user (self object) can travel through and take up position should be clearly defined and match any user expectations
Motivation: Aids the user in planning navigation and approach by providing information about available paths of movement.
Context of use: Generally applicable.
Examples: In an architectural flythrough, a message at the start informs the user that they are in ghost mode and can walkthrough objects and walls. In a training application for submarine familiarisation, navigation is modelled on human walking, where the user cannot walk through objects. Clear corridors are shown between rows of equipment and, when the user collides with an object, a beeping sound is made to indicate that the user cannot pass through.

GDP: **clear self position/state**
Design guideline: The present posture and orientation of the self object should be clearly defined. This incorporates the view angle and the position of individual self parts. The state in which the self is in, if this can change, should be clear
Motivation: Essential to enable the user to be aware of the state of the self object for her to monitor and plan interaction.
Context of use: More important for complex self objects and where the state of the self can change. Not applicable where there is no represented self object and no possible view angle changes.
Examples: In an architectural walkthrough, the present view angle is shown on a stick-man (i.e. head position and present height), represented permanently in the bottom of the screen. In a tourism application, the self can change between a car (for driving through), a plane (for flying around) or a human (for walking around the resort). The current self object is indicated through the use of footstep sounds, car engine sounds and a represented steering wheel, or aeroplane sounds and represented wings.

GDP: **unobstructed navigation pathways**

Design guideline: The valid paths through the environment should be easy for the user to travel through and should be clear of obstructions.

Motivation: Aids the user in carrying out navigation and object approaches easily and efficiently.

Context of use: Generally applicable, unless obstructions have to be maintained for the application domain or task.

Examples: In an architectural flythrough, the navigation style allows the user to walk through objects, such as furniture in a room, but not through walls. In a virtual supermarket application, large empty aisles are provided for navigation. Virtual shopper agents moving along the aisles do not move into the path of the user.

GDP: **appropriate navigation speeds**

Design guideline: The speed at which the user travels should be appropriate to the VE and the navigation tasks of the user. Slower speeds are required for smaller environments and for more precise navigation. Faster speeds are required for large, expansive environments.

Motivation: Aids the user to efficiently and effectively navigate and approach objects in the environment.

Context of use: Generally applicable.

Examples: In an architectural flythrough, the navigation speed adjusts automatically according to the current room. In large, empty rooms a faster speed is used and in small, tighter rooms the speed is reduced. In a tourism application, a default navigation speed is set at a comfortable pace. A function is available for the user to adjust the speed as required, within reasonable limits.

Objects in the vicinity are parts of the VE seen to individually possess functionality and meaning, from the user's point of view.

GDP: **distinguishable object/ object parts**

Design guideline: Objects should be easy to distinguish from all likely viewpoints. Object representations should be distinctive with clear boundaries. Important parts of the object should be easily distinguished from the object image. Inherent ongoing behaviour of the object should be perceivable, e.g. rotations of planet.

Motivation: Necessary to enable the user to perceive individual objects in the environment.

Context of use: More consideration should be given in cluttered environments or where there are many similar looking objects. More consideration should also be given to the more important objects in an environment.

Examples: In an architectural walkthrough, skirting boards and coving are used to separate off walls from floors and ceilings. Walls are separated from one another with different shades of colour and shadows on edges and corners. In a virtual surgery application for training, individual body parts involved in the surgery are shown with a clear outline and exaggerated colours and textures to distinguish them from nearby similar parts.

GDP: **identifiable object/ object parts**

Design guideline: Objects should be easy to identify or recognise. Individual parts of an object, particularly interactive parts, should also be easy to identify and prominent features of objects should be represented. Objects modelled on real world phenomena should be represented accurately and appropriately to match any expectations the user has.

Motivation: Necessary for the user to know what the different objects in the environment are for her to understand and interact effectively with the environment.

Context of use: More consideration should be given to abstract objects (that are not modelled on real world phenomena) or in cases where the user may not have much prior knowledge about an object's identity. More consideration should also be given to the more important objects in an environment.

Examples: In a training application for submarine familiarisation, equipment is represented accurately but not all users have knowledge of submarine equipment so pieces of equipment can be clicked on to get a message identifying the piece of equipment. In a marketing application for a business park, roads are represented with road markings, car park areas with markings for parking spaces, and pathways are represented with paving stones.

GDP: **clear object role**

Design guideline: The purpose or function of objects in the environment should be clearly defined. Relationships with other objects should be clear. The role of objects should meet any user expectations.

Motivation: Aids the user in understanding objects during exploration and plan object interactions.

Context of use: More consideration should be given to abstract objects (not modelled on real world phenomena) or where the user may not have knowledge about the object's role. More consideration should also be given to the more important objects.

Examples: In a marketing application for a business park, information is provided about some services and this is attached to abstract information icon objects placed over/near the related objects/services. The information objects are shown with the standard information 'i' symbol. In a tourist application, virtual people are included in the resort and have label badges indicating their role, such as 'visitor', 'local' and 'travel guide'.

GDP: **clear object type/ significance**

Design guideline: It should be clear to the user whether or not objects can be interacted with. It should also be clear whether objects have the ability to act independently of the user or initiate interactions with the user. The relative importance of objects in the environment and to the user task should be made clear.

Motivation: Provides important information to aid the user understand objects during exploration and plan interactions on interactive objects.

Context of use: More consideration should be given to abstract objects (that are not modelled on real world phenomena) or in cases where the user may not have much prior knowledge about an object. More consideration should also be given to the more important objects in an environment.

Examples: In a marketing application for a business park, a few objects can be interacted with, such as power switches, and these are differentiated from non-active objects, such as power sockets, through the use of bright red outlines. In a tourist application, some virtual people are agents in that they take the initiative to provide information to the user. The agents move around independently in the environment and beckon or approach the user.

GDP: **clear object state**

Design guideline: The state of changeable objects should be clearly defined. Object parts signifying state should be visible and easy to identify.

Motivation: Provides information to aid the user investigate changeable objects and plan interactions with them.

Context of use: More consideration should be given to abstract objects (not modelled on real world phenomena) or where the user may not have knowledge about the object. More consideration should also be given to the more important objects.

Examples: In a marketing application for a business park, power switches in a unit can be on or off. To make the position of the switch more obvious, exaggerated lighting effects are used. To make the 'ON' light more noticeable when it is lit, it is shown in bright red, as opposed to dull red/brown, and is shown slightly larger in size. In a training application for submarine familiarisation, a hatch in the submarine can be open or closed. When closed, a 'how to open' instruction is shown on the hatch and when the hatch is open, the submarine parts above or below are visible through the hatch and the open hatch is shown with a highlighted rim.

GDP: **clear object position/ orientation**

Design guideline: The position and orientation of objects in the environment should be clearly defined.

Motivation: Aids the user in approaching objects and orienting correctly to them when carrying out actions.

Context of use: More consideration should be given in cluttered environments and to objects not resting on a ground or vertical plane. More consideration should also be given to important objects and objects whose position/ orientation in the environment can change.

Examples: In a cluttered virtual office, office furniture is represented with shadows to indicate position and furniture nearer the user is shown in more detail. In an application to learn about the solar system, the orientation of the rotating planets is indicated by including the axis of rotation for each planet and position is indicated through the use of lines of orbit at regular distances from the Sun.

GDP: **accessible object**

Design guideline: Objects should be easy to access, that is, it should be easy for the user to approach objects and take up a suitable position close to objects.

Motivation: Necessary when the user is approaching objects and orienting to objects for investigation or for carrying out actions.

Context of use: More consideration should be given in cluttered environments, where the user is navigating in very restricted areas, or where the user has limited navigation pathways, such as when objects cannot be passed through. More consideration should also be given to the more important objects, such as those that can be interacted with, to the smaller objects and to objects whose position or orientation in the environment can change.

Examples: In a virtual jewellery exhibition, an access function is provided where the user can double click an item of jewellery to be automatically transported to a close up view of the jewellery at a standard orientation. In a marketing application for a business park, in one of the units a water tank is positioned in a loft area. To aid the user approach the tank, a ladder is included leading up to the tank.

System initiative behaviour includes system events and system control. System events are incidents occurring in the vicinity at a particular point in time, having been initiated by the environment system. System control occurs when the system or an agent takes control of the interaction from the user for some reason. Later, control is generally returned to the user.

GDP: **declared system control commencement/ termination**

Design guideline: Whenever the system or an agent takes control of interaction from the user, this should be made clear. It should be clear when control has been returned to the user.

Motivation: Essential for the user to be aware when she no longer has control over some part of her interaction.

Context of use: Generally applicable. More important where significant parts of the user's interaction are affected, such as navigation.

Examples: In a marketing application for a business park, an automated tour of the park is given at the beginning of interaction. A speech track informs the user that the tour is to start and they will be unable to navigate themselves. When the tour ends, another speech track informs the user that the tour has ended. In a virtual surgery application for training, a trainer agent demonstrates surgical procedures. During the demonstration the user cannot practice procedures themselves, therefore, her virtual hands disappear and reappear at the end of the demonstration.

GDP: **clear system control purpose**

Design guideline: The goal of the system in controlling the interaction should be made clear to the user. There should be a clear indication to the user when control is likely to be returned to her.

Motivation: Necessary for the user to understand why the control is taking place so that she can benefit from it in any intended ways. Important for the user to be aware how long the control will last, so she can plan future interactions and plan whether she should attempt to regain control.

Context of use: More important where significant parts of the user's interaction are affected, such as navigation.

Examples: In a marketing application for a business park, a speech track informs the user that an introductory tour follows which will help familiarise her with the park. The speech track also states that the tour will last for 2 minutes. In a virtual surgery application for training, a trainer agent demonstrates surgical procedures to the user. The agent discusses important points of each surgical procedure before demonstrating it.

GDP: **declared available actions during control**
Design guideline: Any actions available to the user during system control should be made clear.
Motivation: Necessary to enable the user to plan interactions during system control and especially plan for regaining control.
Context of use: More important where significant parts of the user's interaction are affected, such as navigation, and with longer durations of control. More important for actions affecting control, such as actions to terminate the control.
Examples: In a marketing application for a business park, an automated tour of the park is given. A speech track informs the user that they cannot navigate during the tour, but can use key 'F10' to quit the tour at any time. The availability of this quit function is also indicated in a text message shown throughout the tour. In a virtual surgery application for training, a trainer agent demonstrates surgical procedures to the user. During demonstrations a set of buttons are displayed on the screen representing available actions, such as 'Stop', 'Replay', 'Switch off commentary'.

GDP: **limited system control**
Design guideline: System control in the environment should not be excessive or intrusive for the user.
Motivation: Necessary so that the user can actively explore the environment.
Context of use: More important where significant parts of the user's interaction are affected, such as navigation, and with longer durations of control. Less applicable where the interaction needs to be largely guided, such as for some training environments or environments for psychological therapy.
Examples: In a marketing application for a business park, an automated tour of the park is included. The tour is only given at the beginning of interaction, provides just a brief introduction to the park and the user has the opportunity to stop the tour at any time. In a virtual surgery application for training, a trainer agent demonstrates surgical procedures to the user. During demonstrations the user cannot practice surgical procedures but can navigate around the demonstration area and can stop the demonstration. The user can also switch to a system mode where they can practice procedures without a prior demonstration.

GDP: **distinguishable behaviour**
Design guideline: System events and ongoing system behaviour should be easy to distinguish, from all likely viewpoints.
Motivation: Necessary for the user to be aware of the system's behaviour which may affect the environment or the self object.
Context of use: Generally applicable. Particularly important for system behaviour affecting the self object or objects significant to the user's task.
Examples: In a virtual office environment, a phone ringing event is represented with a ringing sound that is audible in the room occupied by the ringing telephone and in all neighbouring rooms. In a virtual exhibition, escalators are included which transport the user between floors of the exhibition, through system control. Progress up the escalator is indicated through the use of posters alongside the escalator which come closer to and eventually pass the user, as well as, the movement of the stairs of the escalator.

GDP: **declared causality and effects of behaviour**
Design guideline: The meaning of system events and ongoing system behaviour should be clear and meet any user expectations. This includes the cause of the behaviour, the objects involved in it and the resulting effects to the environment.
Motivation: Necessary for the user to understand the system behaviour and how it has affected the environment or the self object.
Context of use: Particularly important for system behaviour affecting the self object or objects significant to the user's task.
Examples: In an architectural walkthrough, a building has automatic doors. To aid the user in understanding that the doors open automatically as she approaches them, they include a label stating that they are automatic doors. As the doors swing open this is clearly shown and the environment behind them appears in view. In a virtual library, books can be removed by different users or replaced by staff. When books are removed or replaced to the shelf area the user is currently located in, they are shown leaving or going into the book shelves. A message also appears at the bottom of the screen stating which book is now no longer available or is available.

GDP: **clear system activity significance**

Design guideline: The importance of the system event or ongoing system behaviour to the environment and to the user's task should be clearly defined. For events, the temporal urgency of the event, its duration and if the event will be repeated should be clear.

Motivation: Necessary for the user to understand the significance of the system behaviour when she is planning how to respond to the behaviour.

Context of use: Generally applicable, especially if the environment includes a substantial amount of system behaviour which has differing levels of significance and relevance to the user task.

Examples: In a marketing application for a business park, an automated tour of the park is provided. During the tour, units that are available have a 'To Let' sign and the tour drives up to and around these units. Units that are not available have signs such as 'Sold', and the tour just drives past these units. In an architectural walkthrough, a building has automatic doors which stay open for a short time, showing what is available behind them, before closing again. If the user fails to go through the doors, they begin to slowly close, but open fully again with any approach by the user.

GDP: **appropriate response to system activity**

Design guideline: The appropriate user response to system events or to the end of a duration of system control should be clearly defined, such as whether the behaviour can be ignored or needs further investigation. Where the user needs to carry out actions immediately to react to system events, this should be clear.

Motivation: Necessary to enable the user to plan suitable ways to respond to system behaviour.

Context of use: Particularly important if the environment includes a substantial amount of system behaviour which requires different kinds of response.

Examples: In a marketing application for a business park, an automated tour of the park is provided. At the end of the tour a speech track informs the user that the tour is complete and they can navigate and explore the park for themselves. In a virtual library, books can be reserved by the user. When reserved books are available, the reserve shelf is represented over the current view, with the user's book flashing on the shelf and a message appearing at the bottom of the screen describing the book. A prompt also appears asking the user if they would like to take the book on loan.

Actions are sets of operations or activities that the user can carry out in their vicinity, thereby affecting changes in the environment.

GDP: **declared available action**

Design guideline: The availability for action should be made clear to the user.

Motivation: Necessary to aid the user in finding available actions during exploration.

Context of use: Particularly important for exploratory applications. Less applicable where the user has information about actions available in the VE, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In a marketing application for a business park, available actions are highlighted using bright red, a colour not otherwise used in the environment. In a virtual supermarket application, the usual flat hand cursor changes to a 'grab' hand cursor when over available actions, such as when over the supermarket trolley handle, for pushing the trolley, and when over items of shopping.

GDP: **clear action purpose**

Design guideline: It should be made clear to the user what each action is for, that is the resulting effect of an action, and this should meet any expectations the user may have.

Motivation: Aids the user understand the purpose of each action. This is necessary during exploration and when the user is assessing the relevance of actions to the her task and goals.

Context of use: Particularly important for exploratory applications. Less applicable where the user has information about actions available in the VE, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In an architectural walkthrough, doors are labelled to inform the user what the action of opening each door will bring into view. In a marketing application for a business park, actions are available which provide information on various features of the premises. To indicate the provision of information, 'i' icons are placed over/next to relevant objects.

GDP: **clear self/object orientation for action**

Design guideline: The required orientation to objects for carrying out actions should be clear to the user and should meet any user expectations.

Motivation: Aids the user in carrying out actions by making clear what alignment is required between parts of the self and action objects, when approaching the action objects.

Context of use: Important with more complex action sequences, where particular self parts and particular object parts need to be aligned. Less applicable where the user has information about the action sequence, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In a virtual surgery training application, the self object can be attached to various tools. For surgical operations, the alignment required between a tool and body part is indicated by displaying an outline of the tool next to the body part in the correct orientation to be attained. In a teleoperation application to remotely maintain satellites, alignment of remote robots with the satellite is aided by displaying a line linking the relevant satellite and robot parts.

GDP: **declared action sequence**

Design guideline: The sequence of operations required to carry out actions should be clearly defined and match any expectations the user may have.

Motivation: Essential for the user to know what operations are required to carry out actions. Avoids forcing the user to resort to guesswork when carrying out actions.

Context of use: Particularly important with more complex action sequences, involving multiple operations or components, or a choice of interaction styles such as click/drag/double-click. Less applicable where the user has information about the action sequence, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In a virtual business park, a drawing board showing plan layouts of buildings has an action associated to it for tilting the board. Information is available explaining how to tilt the board - using a handle at the side to loosen the board and then dragging the board itself. Also the user is lead through the action sequence, in that initially the handle alone is highlighted as available for manipulation. When the board has been loosened, the board itself is also highlighted as available for manipulation. In an engine assembly training application, an animated demonstration is shown to inform the user how to carry out particular assembly actions. The demonstration shows how the parts of the user representation, virtual tools and objects parts are involved in the action sequence.

GDP: **executable action**

Design guideline: Actions should be efficient to execute and there should not be frequent obstacles/problems in executing actions. The action sequence should be as simple as possible. The demand of manipulation precision and motor co-ordination should be within usual human ability.

Motivation: Essential for the user to be able to execute actions. Also, the user needs a high level of control over the action execution so that she can easily achieve the effect she wants.

Context of use: Generally necessary for all actions. Particular consideration needs to be given for actions sequences that have a long duration or complex actions which may require precise and difficult manipulations. More consideration also needs to be given for more common actions, such as navigation.

Examples: In a virtual business park, a drawing board showing plan layouts of buildings has an action associated to it for tilting the board. A small handle is manipulated to loosen the board for tilting. The handle is manipulated with a simple click operation (rather than dragging the handle back). The handle is also represented in a larger size and a wider area around the handle is highlighted to make pointing to the handle easier. In an architectural walkthrough, doors are made easier to navigate through by making the areas around door openings act as guides which push the user towards the centre of the door opening, when within a near enough region. Also, a virtual hand shows the left-most point of the user position which can be used to help align with the door opening.

GDP: **reversible action effect**

Design guideline: The effect of actions should be easy to undo.

Motivation: Aids the user in correcting errors made when carrying out actions. Also encourages exploration by making exploratory actions easy to recover from.

Context of use: More important for actions that are difficult to execute, such as those that require precise and difficult manipulations or those that have a long duration. May particularly apply to training and learning applications.

Examples: In an engine assembly training application, there is a function available to undo the last operation. In a virtual supermarket application, the user can click on items in the trolley to deselect them, in which case they are automatically returned to the shelf.

Action feedback are changes presented in the environment resulting from actions carried out. As well as feedback after an action has been carried out, there may be feedback whilst an action is being carried out for long, slow actions.

GDP: **clear action progress**

Design guideline: Feedback on the effects of actions as they are being carried out should be given and should be easily distinguished by the user. The feedback should be timely, accurate and integrated across all modalities (vision, sound etc.) used.

Motivation: Important that the user can see the effects of actions whilst she is executing them, so that progress in carrying out the actions can be assessed.

Context of use: Important for long or slow actions and for complex action sequences, involving multiple operations or components. Less important for actions carried out instantly, such as single mouse clicks.

Examples: In a virtual office, the printout from a printer can be read by lifting up the printout and dragging it towards the centre of the viewpoint. During this action, the selection of the printout is indicated by highlighting the printout and showing it attached to the virtual hand. The changing position of the printout is shown throughout whilst the printout is being dragged towards the self. In a virtual chemistry experiment, as the user is mixing chemicals, ongoing chemical effects are indicated through visual changes in the amount/appearance of chemicals and concurrent sound effects.

GDP: **clear during action effects**

Design guideline: The meaning of feedback during actions should be clear to the user and meet any user expectations.

Motivation: Important that the user can understand, as well as see, the effects of actions whilst she is executing them, so that progress in carrying out the actions can be judged.

Context of use: Important for long or slow actions and for complex action sequences, involving multiple operations or components. Less important for actions carried out instantly, such as single mouse clicks. Less applicable where the user has information about the meaning of action feedback, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

Examples: In a virtual supermarket, items can be grabbed by the virtual hand and dragged into the trolley. During this action, the item is shown as being clearly picked up and moved around by the hand, and then placed into the trolley. In a virtual chemistry experiment, as the user is mixing chemicals, an ongoing soundtrack explains the perceivable changes and what is happening to the chemicals involved in the experiment. To meet user expectations all expected sound effects, such as fizzing, are included.

GDP: **declared action effect/ success**

Design guideline: Feedback on the effects of completed actions should be given and should be easy for the user to distinguish. The feedback should be timely, accurate and integrated across all modalities (vision, sound etc.) used.

Motivation: Important that the user can see the effects of actions that she has carried out, so that the success of actions can be assessed and any errors detected.

Context of use: Generally required for all actions. More consideration needs to be given for complex actions with multiple or varying effects.

Examples: In a virtual business park, power switches can be turned on or off. The power switches jump to indicate when they have been clicked. Also, a light on the switches changes in colour and the position of the switches changes - and these effects are accentuated by using very obvious changes in colour and shade. In a virtual office, a printer can be activated. When the printer starts to print, the printout is not seen until it has been fed through the printer. However, sounds of the printer are immediately heard and running parts of the printer are shown moving.

GDP: **clear action effect**

Design guideline: The meaning of feedback after actions are complete should be clear to the user and meet any user expectations.

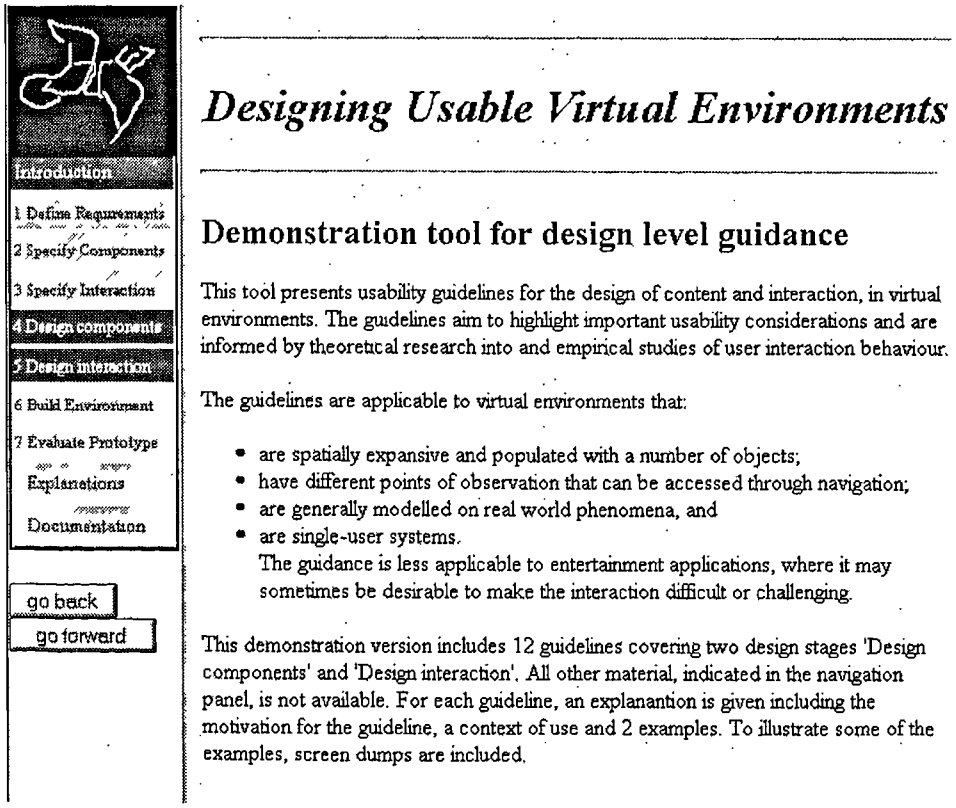
Motivation: Important that the user can understand, as well as see, the effects of actions that she has carried out, so that the success of actions can be judged and any errors understood.

Context of use: More consideration needs to be given for complex actions with multiple or varying effects. Less applicable where the user has information about action feedback, for example as in the case of VEs accurately modelling activities in a domain well known to the user.

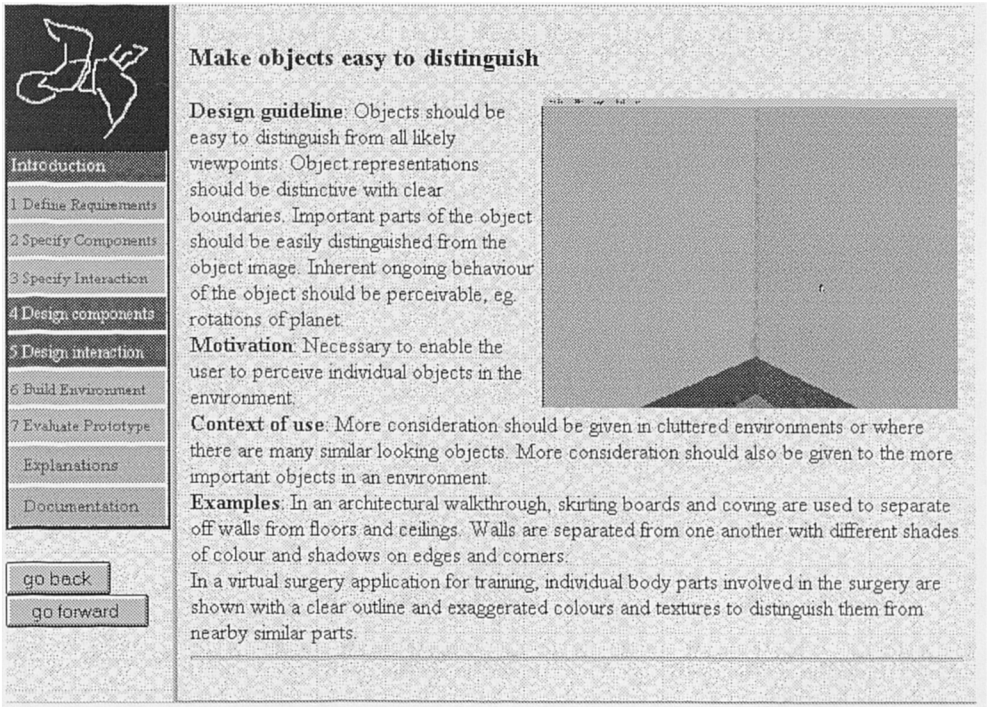
Examples: In a virtual business park, power switches can be turned on or off. When the power switches have been turned on, a light on the switches changes to bright red to indicate on. When all required power switches have been turned on, machinery in the factory area begins running. This is indicated by the movements of the, remotely located, machinery and the immediately audible sounds of the machinery. In an architectural walkthrough, certain floor areas have a special covering. Information is available about the floor covering and, when this information is displayed, the floor area being referred to is indicated by highlighting it whilst the information is displayed, and then for a short while afterwards. Covered floor areas are also permanently shown in a specific texture.

Appendix 6B: Hypertext in the demonstration version of the guidance tool

Introduction page:



Design components page:



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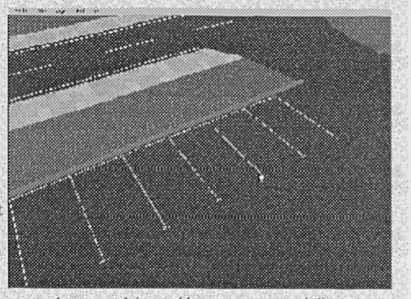
Make objects easy to identify



Design guideline: Objects should be easy to identify or recognise. Individual parts of an object, particularly interactive parts, should also be easy to identify and prominent features of objects should be represented. Objects modelled on real world phenomena should be represented accurately and appropriately to match any expectations the user has.
Motivation: Necessary for the user to know what the different objects in the environment are for her to understand and interact effectively with the environment.
Context of use: More consideration should be given to abstract objects (that are not modelled on real world phenomena) or in cases where the user may not have much prior knowledge about an object's identity. More consideration should also be given to the more important objects in an environment.
Examples: In a training application for submarine familiarisation, equipment is represented accurately but not all users have knowledge of submarine equipment so pieces of equipment can be clicked on to get a message identifying the piece of equipment.
In a marketing application for a business park, roads are represented with road markings, car park areas with markings for parking spaces, and pathways are represented with paving stones.

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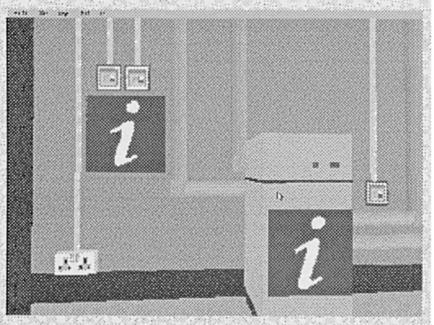
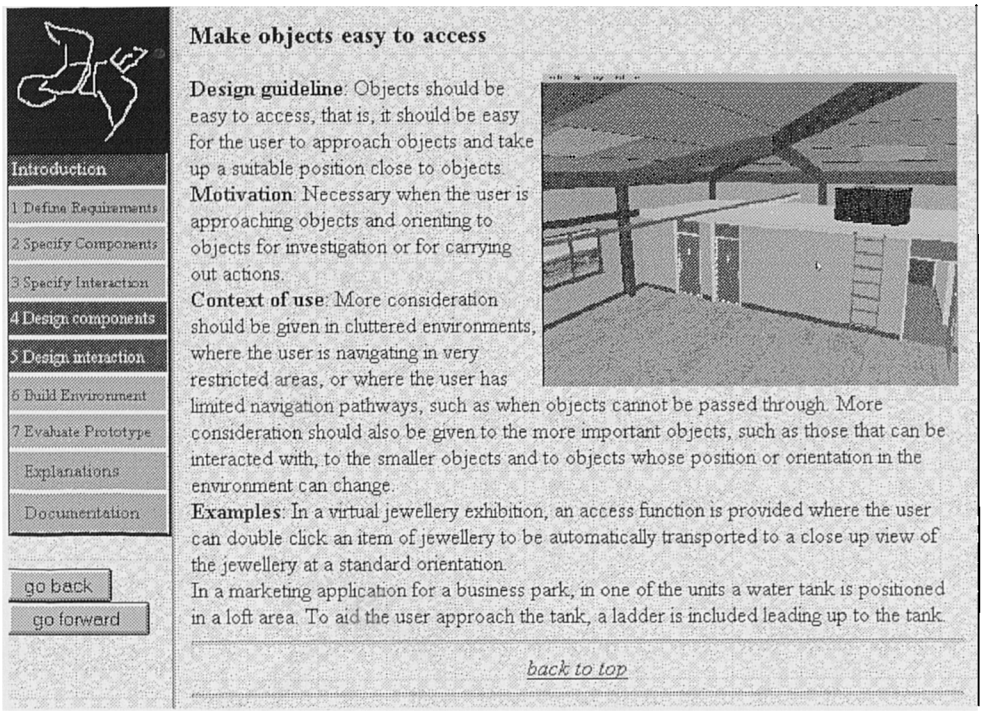
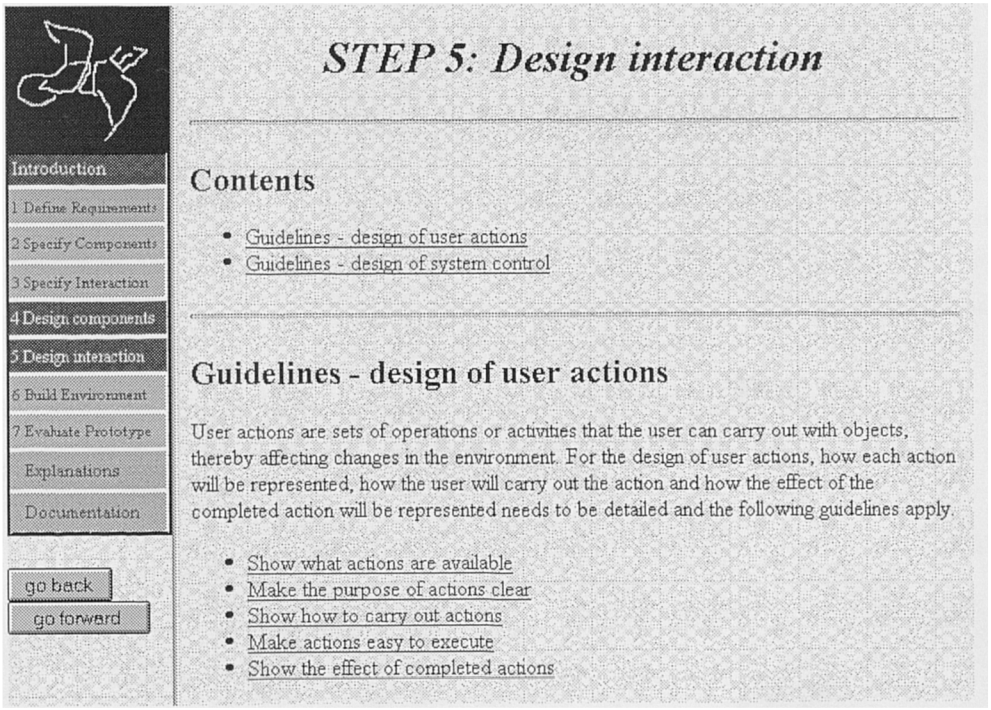
Make the interactivity and significance of objects clear



Design guideline: It should be clear to the user whether or not objects can be interacted with. It should also be clear whether objects have the ability to act independently of the user or initiatiate interactions with the user. The relative importance of objects in the environment and to the user task should be made clear.
Motivation: Provides important information to aid the user understand objects during exploration and plan interactions on interactive objects.
Context of use: More consideration should be given to abstract objects (that are not modelled on real world phenomena) or in cases where the user may not have much prior knowledge about an object. More consideration should also be given to the more important objects in an environment.
Examples: In a marketing application for a business park, a few objects can be interacted with, such as power switches, and these are differentiated from non-active objects, such as power sockets, through the use of bright red outlines.
In a tourist application, some virtual people are agents in that they take the initiative to provide information to the user. The agents move around independently in the environment and beckon or approach the user.



Design interaction page:



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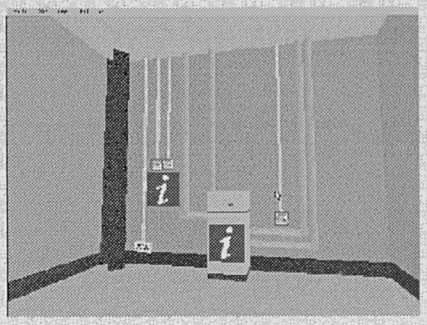
Show what actions are available



Design guideline: The availability for action should be made clear to the user.
Motivation: Necessary to aid the user in finding available actions during exploration.
Context of use: Particularly important for exploratory applications. Less applicable where the user has information about actions available in the VE, for example as in the case of VEs accurately modelling activities in a domain well known to the user.
Examples: In a marketing application for a business park, available actions are highlighted using bright red, a colour not otherwise used in the environment.
In a virtual supermarket application, the usual flat hand cursor changes to a 'grab' hand cursor when over available actions, such as when over the supermarket trolley handle, for pushing the trolley, and when over items of shopping.

Make the purpose of actions clear

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Make the purpose of actions clear

Design guideline: It should be made clear to the user what each action is for, that is the resulting effect of an action, and this should meet any expectations the user may have.
Motivation: Aids the user understand the purpose of each action. This is necessary during exploration and when the user is assessing the relevance of actions to the her task and goals.
Context of use: Particularly important for exploratory applications. Less applicable where the user has information about actions available in the VE, for example as in the case of VEs accurately modelling activities in a domain well known to the user.
Examples: In an architectural walkthrough, doors are labelled to inform the user what the action of opening each door will bring into view.
In a marketing application for a business park, actions are available which provide information on various features of the premises. To indicate the provision of information, 'i' icons are placed over/next to relevant objects.

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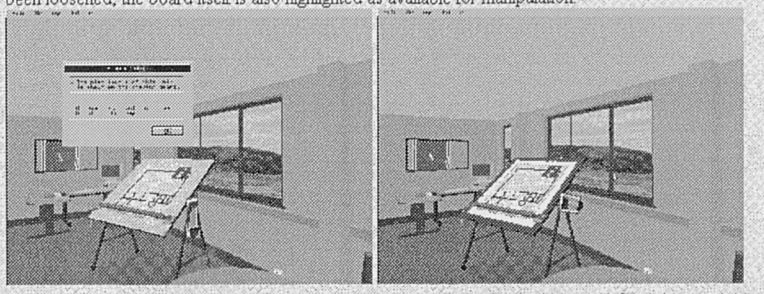
Show how to carry out actions

Design guideline: The sequence of operations required to carry out actions should be clearly defined and match any expectations the user may have.
Motivation: Essential for the user to know what operations are required to carry out actions. Avoids forcing the user to resort to guesswork when carrying out actions.
Context of use: Particularly important with more complex action sequences, involving multiple operations or components, or a choice of interaction styles such as click/drag/double-click. Less applicable where the user has information about the action sequence, for example as in the case of VEs accurately modelling activities in a domain well known to the user.
Examples: In a virtual business park, a drawing board showing plan layouts of buildings has an action associated to it for tilting the board. Information is available explaining how to tilt the board - using a handle at the side to loosen the board and then dragging the board itself. Also the user is lead through the action sequence, in that initially the handle alone is highlighted as available for manipulation. When the board has been loosened, the board itself is also highlighted as available for manipulation.



In an engine assembly training application, an animated demonstration is shown to inform the user how to carry out particular assembly actions. The demonstration shows how the parts of the user representation, virtual tools and objects parts are involved in the action sequence.

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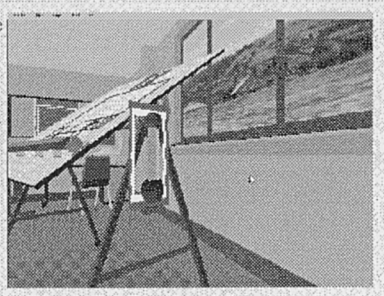
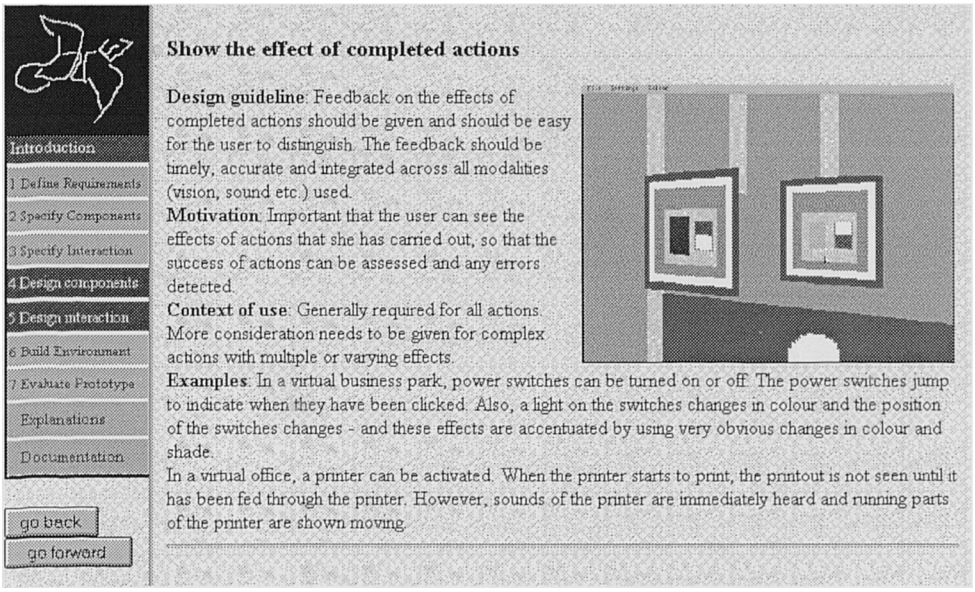
Make actions easy to execute



Design guideline: Actions should be efficient to execute and there should not be frequent obstacles/problems in executing actions. The action sequence should be as simple as possible. The demand of manipulation precision and motor co-ordination should be within usual human ability.
Motivation: Essential for the user to be able to execute actions. Also, the user needs a high level of control over the action execution so that she can easily achieve the effect she wants.
Context of use: Generally necessary for all actions. Particular consideration needs to be given for actions sequences that have a long duration or complex actions which may require precise and difficult manipulations. More consideration also needs to be given for more common actions, such as navigation.
Examples: In a virtual business park, a drawing board showing plan layouts of buildings has an action associated to it for tilting the board. A handle is manipulated to loosen the board for tilting. The handle is manipulated with a simple click operation (rather than dragging the handle back). The handle is also represented in a larger size and a wider area around the handle is highlighted to make pointing to the handle easier.
In an architectural walkthrough, doors are made easier to navigate through by making the areas around door openings act as guides which encourage the user towards the centre of the door opening, when within a near enough region. Also, a virtual hand shows the left-most point of the user position which can be used to help align with the door opening.


Introduction
1 Define Requirements
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3 Specify Interaction
4 Design components
5 Design interaction
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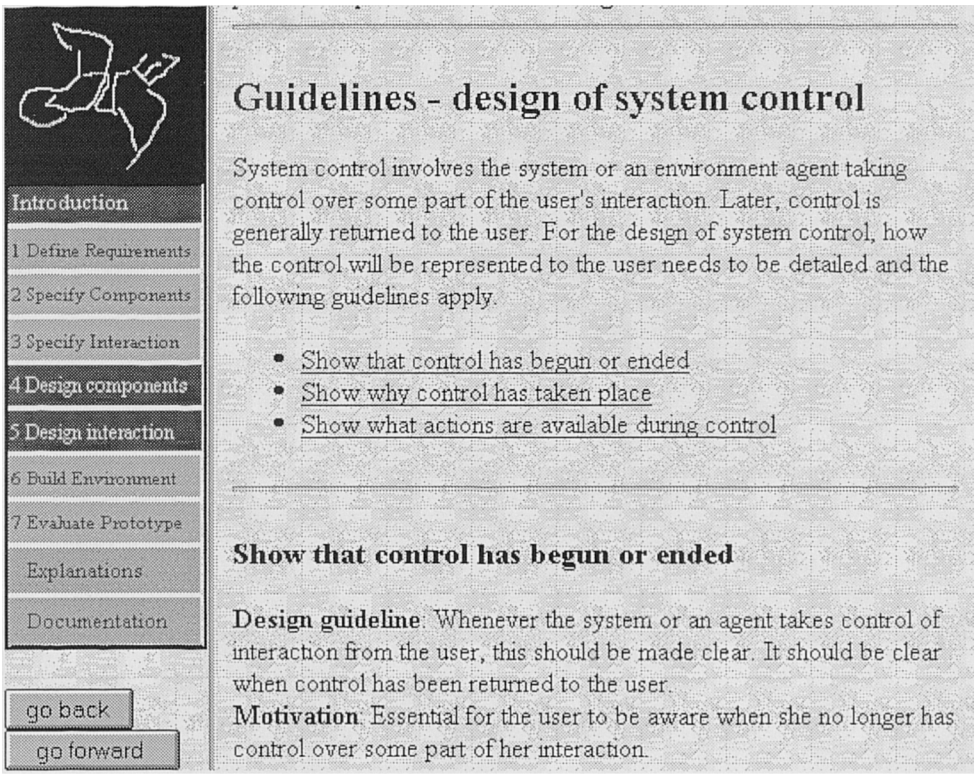
Show the effect of completed actions
Design guideline: Feedback on the effects of completed actions should be given and should be easy for the user to distinguish. The feedback should be timely, accurate and integrated across all modalities (vision, sound etc.) used.
Motivation: Important that the user can see the effects of actions that she has carried out, so that the success of actions can be assessed and any errors detected.
Context of use: Generally required for all actions. More consideration needs to be given for complex actions with multiple or varying effects.
Examples: In a virtual business park, power switches can be turned on or off. The power switches jump to indicate when they have been clicked. Also, a light on the switches changes in colour and the position of the switches changes - and these effects are accentuated by using very obvious changes in colour and shade.
In a virtual office, a printer can be activated. When the printer starts to print, the printout is not seen until it has been fed through the printer. However, sounds of the printer are immediately heard and running parts of the printer are shown moving.


Introduction
1 Define Requirements
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Guidelines - design of system control
System control involves the system or an environment agent taking control over some part of the user's interaction. Later, control is generally returned to the user. For the design of system control, how the control will be represented to the user needs to be detailed and the following guidelines apply.
Show that control has begun or ended
Show why control has taken place
Show what actions are available during control
Show that control has begun or ended
Design guideline: Whenever the system or an agent takes control of interaction from the user, this should be made clear. It should be clear when control has been returned to the user.
Motivation: Essential for the user to be aware when she no longer has control over some part of her interaction.

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Show that control has begun or ended

Design guideline: Whenever the system or an agent takes control of interaction from the user, this should be made clear. It should be clear when control has been returned to the user.
Motivation: Essential for the user to be aware when she no longer has control over some part of her interaction.
Context of use: Generally applicable. More important where significant parts of the user's interaction are affected, such as navigation.
Examples: In a marketing application for a business park, an automated tour of the park is given at the beginning of interaction. A speech track informs the user that the tour is to start and they will be unable to navigate themselves. When the tour ends, another speech track informs the user that the tour has ended.

"Welcome to Rural Wales Newtown site.
There now follows an automated drive
to introduce you to the site." *ongoing speech track at start*

"The drive through is now complete
and you may use your joystick
to navigate through the world." *at end*

In a virtual surgery application for training, a trainer agent demonstrates surgical procedures. During the demonstration the user cannot practice procedures themselves, therefore, her virtual hands disappear and reappear at the end of the demonstration.

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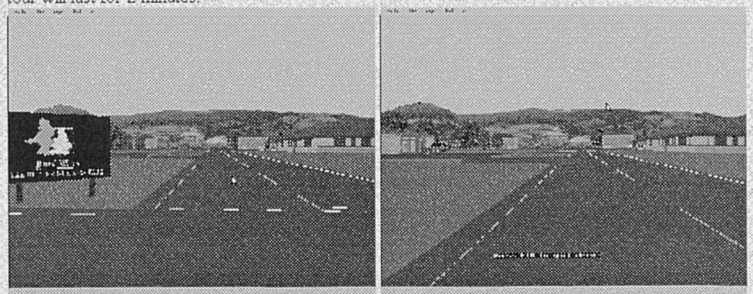
Show why control has taken place

Design guideline: The goal of the system in controlling the interaction should be made clear to the user. There should be a clear indication to the user when control is likely to be returned to her.
Motivation: Necessary for the user to understand why the control is taking place so that she can benefit from it in any intended ways. Important for the user to be aware how long the control will last so she can for plan future interactions and plan whether she should attempt to regain control.
Context of use: More important where significant parts of the user's interaction are affected, such as navigation.
Examples: In a marketing application for a business park, a speech track informs the user that an introductory tour follows which will help familiarise her with the park. The speech track also states that the tour will last for 2 minutes.



"Welcome to Rural Wales Newtown site.
There now follows an automated drive
to introduce you to the site." *ongoing speech track*

"The drive through will last about 2 minutes
during which you will be unable
to navigate using your joystick."

In a virtual surgery application for training, a trainer agent demonstrates surgical procedures to the user. The agent discusses important points of each surgical procedure before demonstrating it.

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3 Specify Interaction
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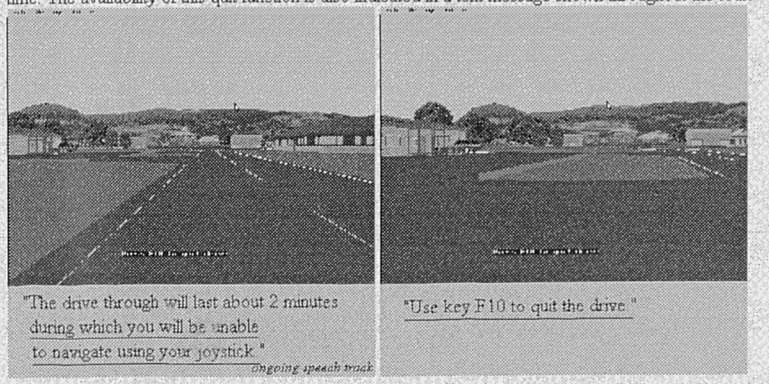
Show what actions are available during control

Design guideline: Any actions available to the user during system control should be made clear.
Motivation: Necessary to enable the user to plan interactions during system control and especially plan for regaining control.
Context of use: More important where significant parts of the user's interaction are affected, such as navigation, and with longer durations of control. More important for actions affecting control, such as actions to terminate the control.
Examples: In a marketing application for a business park, an automated tour of the park is given. A speech track informs the user that they cannot navigate during the tour, but can use key 'F10' to quit the tour at any time. The availability of this quit function is also indicated in a text message shown throughout the tour.



"The drive through will last about 2 minutes during which you will be unable to navigate using your joystick."
ongoing speech track

"Use key F10 to quit the drive."

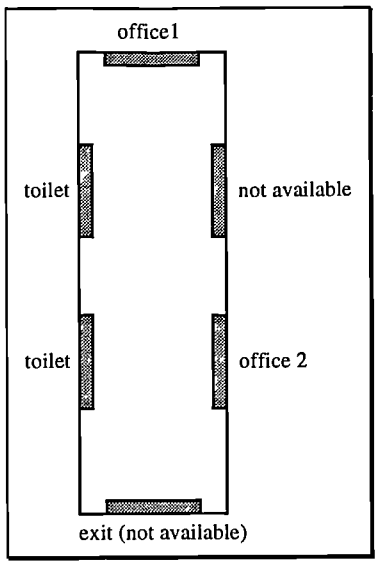
In a virtual surgery application for training, a trainer agent demonstrates surgical procedures to the user. During demonstrations a set of buttons are displayed on the screen representing available actions, such as 'Stop', 'Replay', 'Switch off commentary'.

Appendix 6C: Design scenarios

Scenarios 1

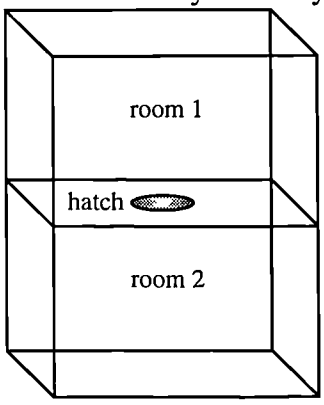
Design object 1

For a virtual office application, design a corridor with various doors (as shown). Some of the doors can be opened and lead into rooms indicated. Other doors are not available. Navigation is modelled on human walking, where objects cannot be passed through but the height and view angle can be changed. Design a representation of the corridor and its doors, using storyboards. Remember to think about any usability issues involved.



Design object 2

For a virtual submarine application, design a hatch which connects two rooms, one above the other (as shown). The hatch can be opened and closed. The area surrounding the hatch is coloured different shades of grey in both rooms. In room 1, the hatch is surrounded by walls and, in room 2, the hatch is surrounded by walls, equipment and a ladder. In the navigation paradigm used, objects cannot be passed through. Design a representation of the hatch (only), using storyboards. Remember to think about any usability issues involved.



Scenarios 1

Design action 1
Continuing with the virtual submarine application above..
Input devices available are a 2D mouse, keyboard and joystick. Design the interaction for the user action of opening/closing the hatch, using storyboards. Remember to think about any usability issues involved.

Design action 2
For a virtual office application, design an action to produce and read output from a printer. The action should enable the user to initiate a standard printout, using a printer object, and then view the printout so as to be able to read its contents. Input devices available are a 2D mouse, keyboard and joystick. Design the interaction for the user action of producing and reading the printout, using storyboards. Specify any details of the printer representation relevant to the user action, but do not design the complete printer object. Remember to think about any usability issues involved.

Design system control
For a virtual tourism application, design a system control where, upon beginning interaction, the user is first shown around a town. In the system control, the user is automatically taken to places of interest and cannot navigate independently. At a place of interest, some information is provided and then the user is taken to the next place. However, the user may request some time to explore the place of interest by themselves and then re-initiate the tour, or the user can request to quit the system control and return to their starting point. Input devices available are a 2D mouse, keyboard and joystick. Design the system control of the guided tour of a town, using storyboards. Specify any relevant object representation and user action details. Remember to think about any usability issues involved.

Scenarios 2

For this section, I would like you to choose interesting or typical design scenarios from your previous experiences and try out the guideline tool with these scenarios. Choose 2 scenarios which involved either the design of an object, action or system control. Describe each scenario and then storyboard the details of your new design, from using the tool. Take into account the type of virtual environments addressed by the tool (detailed in the introduction page) when choosing your scenarios.

Scenario 2a

Object, action or system control?

Description

Scenario 2b

Object, action or system control?

Description

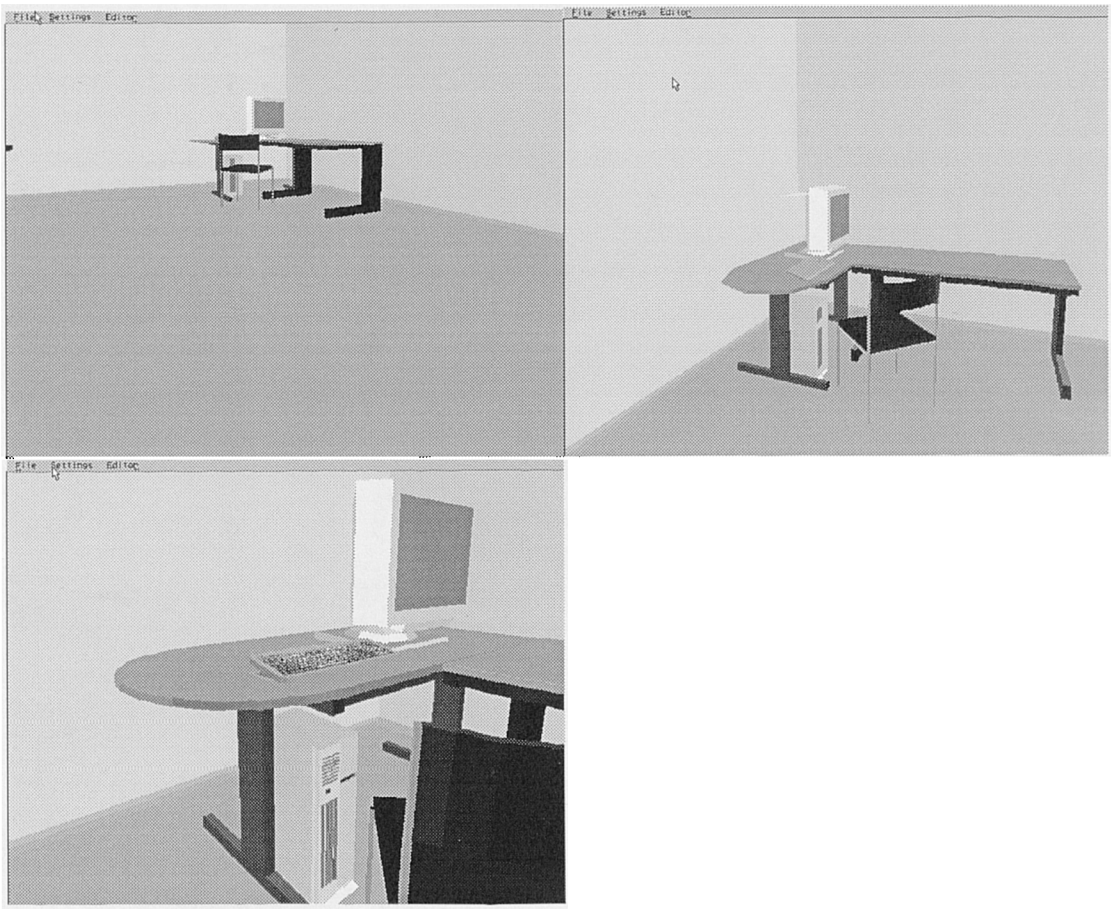
Scenarios 3

Re-design object

In a virtual office application, there is a personal computer object that has been designed as shown in the screen dumps overleaf. The PC object is included as example furniture in the virtual office and therefore does not have any associated actions *(and this is not to change).* Navigation in the environment is modelled on human walking, where objects cannot be passed through but the height and view angle can be changed. From usability testing, the following problems have been found:

- From some positions around and distances from the PC, users do not know what this object is.
- The majority of users try repeatedly interacting with the PC, expecting to find some activity associated with it. They commonly try interacting with the monitor screen, buttons on the keyboard and flashing (hard disk) lights on the PC.
- Although the PC is just example furniture, users seem to be attracted to it, appearing to attach unexpected importance to it.
- Some users have difficulty getting close to the PC to examine it.

Re-design the representation of the PC, using storyboards. Use the guidance in the tool and take into account the above problems.



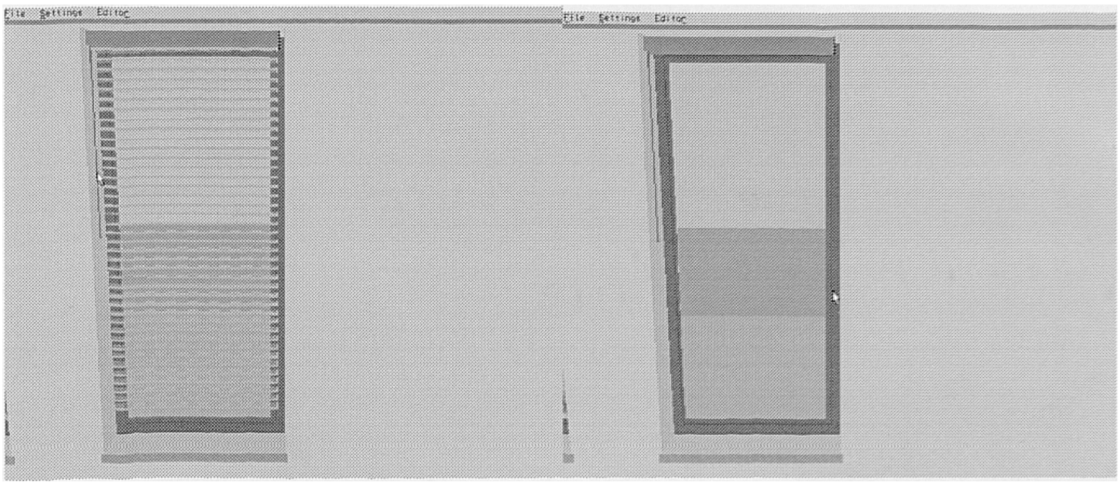
Scenarios 3

Re-design action

In the virtual office, there is a blind that has been designed as shown in the screen dumps overleaf. The blind can be interacted with by clicking the mouse on the shorter, left rod, to rotate the slats. The top grey panel of the blind can also be used to rotate the slats. By clicking on the longer, right rod the blind can be drawn up and down. From usability testing, the following problems have been found:

- Many users do not realise that the blind is interactive and therefore do not try out its interactions.
- For those that do try interacting with the blind, many click on the slats themselves, expecting to initiate interaction this way.
- Some users then try out the rods, but are not sure which rod will do what and have to experiment with them.
- They have difficulty precisely positioning the mouse pointer on the rods to interact with them.
- Users are confused when they find that clicking on the short rod or clicking on the grey panel appears to have the same effect. They try these interactions again looking for any differences.
- Users sometimes want to draw the blind halfway which is not possible. They try clicking on the long rod again when the blinds are being drawn up, expecting that this may stop the blind being drawn up any further. However, instead of stopping the blind, the blind repeatedly draws up or down completely, according to how many times the rod has been clicked.

Re-design the interactions of the blind, using storyboards. Use the guidance in the tool and take into account the above problems.



Appendix 6D: Background questionnaire

Name	
Organisation	
Role in organisation	
Age	
Sex (M/F)	

Background

Area	**Please tick if relevant**	**Give Details**
computing/programming		
electronics		
computer graphics		
architecture/CAD		
human-computer interaction		
Other (give details)		

VR experience

number years experience	

Application areas worked on

Area	**Please tick if relevant**	**Give Details**
Product Design/Evaluation		
Marketing		
Training		
Education		
Entertainment		
Information visualisation		
Groupware/CSCW		
Teleoperation		
Other (give details)		

Software tools used

Tool	**Please tick if relevant**
Superscape VRT	
Division dvise	
MEDIT	
other (give details)	

Do you use-

	Please tick if relevant	**Give Details**
storyboarding or sketching of designs		
existing system development methods or guidelines		

Appendix 6E: Storyboarding guidance notes

Definition
Storyboards are sequences of sketches showing the screen and actions the user would take at key points in the task (Lewis and Rieman, 1993).

Storyboards are used by designers during the early stages of user-interface design (from survey by Landay and Myers).

Examples (see overleaf)

For your storyboards you can use
- pencil and paper
- powerpoint
- superscape

but I will need a copy of your storyboards for later analysis.

Each storyboard should include accompanying text to describe design details. Also the following should be included:
for objects
1. representation details of object
2. details of surroundings of object
3. details of the navigation paradigm
4. any relevant support functions

for actions
1. representation details of relevant objects
2. breakdown of operations involved in action, including
   - how action is carried out;
   - system feedback from every operation;
   - details of constraints or limitations on the action execution, and
   - operations and feedback to be time sequenced
3. modalities used, other than visual, to be indicated
4. any relevant support functions

for system control
1. breakdown of system behaviours - start to finish & time sequenced
2. representation details of relevant objects
3. operations involved in related user actions
4. modalities used, other than visual, to be indicated
5. any relevant support functions

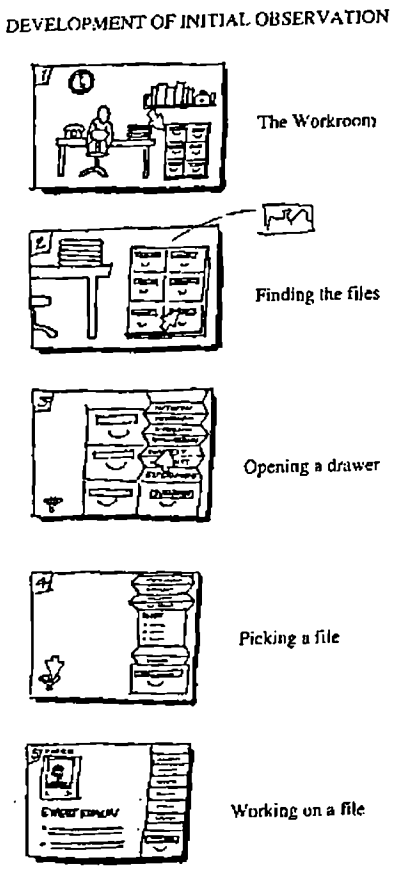


Figure 8.8. A storyboard describing a refinement of the file cabinet functionality.

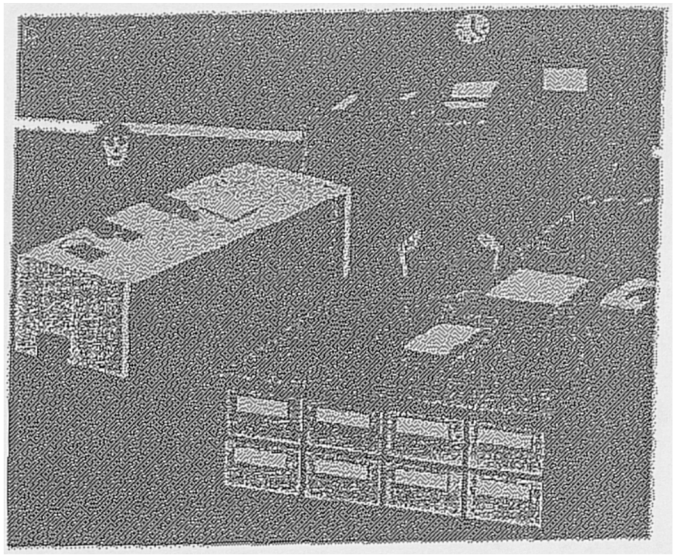


Figure 8.10. Screen shot from a version of the workroom prototype.

Appendix 6F: Retrospective questionnaire

Name:_____

Instructions:
Please answer all questions. For some questions a scale of 1 to 7 is given. Circle the most appropriate number. Give comments and examples with your answers, as indicated. Use the notes you made while carrying out the scenarios to help answer questions. You may also refer to the guidelines tool.

****

1. How easy did you find it to access relevant guidance in the tool?
eg. knowing where all relevant guidance was in the tool, for a particular design problem
getting to the relevant guidance in the tool
examples where guidance was easy and difficult to access, if relevant
Comments:

2. How easy did you find the guidelines to understand?
eg. the language used to describe the guidelines
how well you understood the overall guideline messages
how well you understood other parts, such as examples
how many of the guidelines you understood
examples of guidelines easy and difficult to understand, if relevant
Comments:

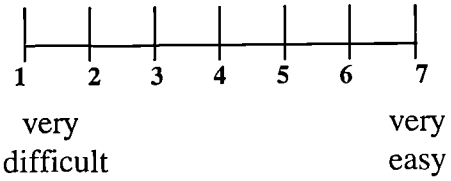
3. How easy did you find the guidance in the tool to apply to the design scenarios

eg. knowing what was required to meet the guidelines in the tool
translating the requirements for your specific design problems
coming up with ways to address the guideline issues for your specific design problems
examples of guidelines easy and difficult to apply, if relevant, & for which scenarios

for:

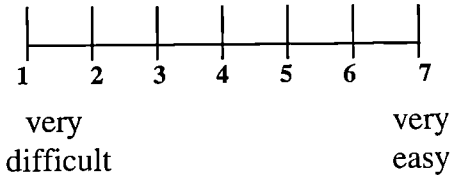
objects

Comments:



actions

Comments:



system control

Comments:

4. How appropriate did you find the level of description, on a possible scale from general to specific, that the guidance was pitched at?

eg. whether guidelines in general too vague, too rigid, or pitched right
examples of guidelines too vague for effective guidance, if relevant
examples of guidelines too rigid and specific for different design scenarios, if relevant
examples of guidelines felt to be pitched right, if relevant

Comments:

not appropriate — very appropriate

5. Was there any conflicting advice you found in the tool? If so, what and how did you handle the conflicts?

6. How acceptable do you feel the guidance in the tool would be if incorporated with your established design practices?

eg. compatibility of using the tool within current design procedures
changes required to current practices if use the tool

Comments:

not acceptable — very acceptable

****

7.Which guidelines did you use for the different design scenarios?

object guidelines	*used?*	*design scenarios where used*
Make objects easy to distinguish		
Make objects easy to identify		
Make the interactivity and significance of objects clear		
Make objects easy to access		
action guidelines		
Show what actions are available		
Make the purpose of actions clear		
Show how to carry out actions		
Make actions easy to execute		
Show the effect of completed actions		
system control guidelines		
Show that control has begun or ended		
Show why control has taken place		
Show what actions are available during control		

Comments:

8. How useful did you find the guidance in the tool in highlighting or uncovering usability issues for the different design scenarios?

eg. how many issues were uncovered/highlighted by the tool, per design scenario
how many issues did you know and were going to address anyway, give examples
how many did you know about but had forgotten & the tool reminded you, give examples
how many issues were new to you, give examples

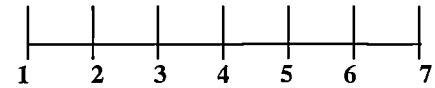
Comments:

not useful very useful

9. How useful did you find the guidance in the tool in helping to address usability issues for the different design scenarios

eg. how many issues did the tool help you to address by generating your own ideas/solutions
any cases where you directly reused from the guideline examples to address issues
examples of issues uncovered but that you could not address with the tool, if relevant
problems you had in using the tool to address usability issues

Comments:



not useful very useful

10. How useful did you find the guidance in the tool in helping to validate designs from a usability perspective?

eg. did you validate the usability of design solutions
how many designs did the tool help you to validate the usability of
examples where the tool was useful in validating designs, if relevant
examples of designs that you found difficult to validate with the tool, if relevant
any problems you had in using the tool to validate the usability of design solutions

Comments:

not useful — very useful

11. What level of improvement in overall usability did you perceive the use of the guidance in the tool led to with the different design scenarios?

eg. for how many designs did you perceive usability to have been improved
how you would judge the level of usability in design solutions
examples where usability felt to be improved and how, if relevant
examples where usability felt not to be improved, if relevant

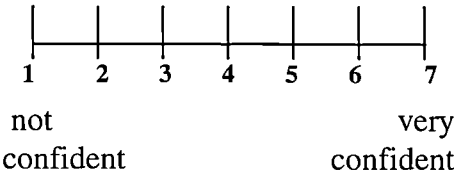
Comments:

not improved — much improved

12. How confident were you in the validity of the guidance in the tool?

eg. how correct or true did you feel the guidance in the tool was and why
examples of guidance where unsure about validity, if relevant

Comments:

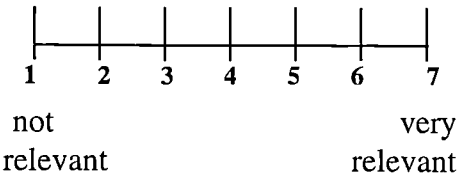


****

13. How relevant do you feel the design scenarios are compared with your experiences in virtual environment design?

include. any examples of seemingly irrelevant design scenarios

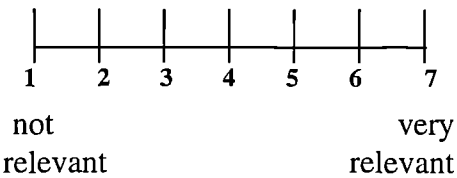
Comments:



14. How relevant do you feel the examples in the tool are compared with your experiences in virtual environment design?

include. any seemingly irrelevant examples

Comments:



15.What improvements, if any, do you feel are required to the tool?