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On the role of individual human abilities in the design of adaptive user interfaces for scientific problem solving environments

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Abstract A scientific problem solving environment should be built in such a way that users (scientists) might exploit underlying technologies without a specialised knowledge about available tools and resources. An adaptive user interface can be considered as an opportunity in addressing this challenge. This paper explores the importance of individual human abilities in the design of adaptive user interfaces for scientific problem solving environments. In total, seven human factors (gender, learning abilities, locus of control, attention focus, cognitive strategy and verbal and nonverbal IQs) have been evaluated regarding their impact on interface adjustments done manually by users. People's preferences for different interface configurations have been investigated. The experimental study suggests criteria for the inclusion of human factors into the user model guiding and controlling the adaptation process. To provide automatic means of adaptation, the Intelligent System for User Modelling has been developed.

Keywords Scientific problem solving environments · Adaptive user interfaces · Human factors · Experimental study

1 Introduction

A problem solving environment (PSE) is a computer-based interactive framework that combines software and hardware resources to help users in solving a target class of problems [18]. Usually, PSEs are tailored to specific application areas.

A scientific PSE (SPSE) is aimed to facilitate the exploration of scientific data. It puts the user into an experimental cycle simulated by a computer and let him/her apply expertise to find better solution tothe targeted problem. MATLAB,

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STATISTICA and RLAB are among the most well-known SPSEs. SPSEs enable users to explore problems in areas as diverse as plasma physics, gas dynamics, cosmology, airshed modelling, etc. Sometimes, SPSEs can also assist in scientific decision making.

The ultimate goal of a PSE is to allow a user to find a solution to the problem as quickly as possible. The primary SPSE users are domain experts investigating a scientific phenomenon and trying to predict its behaviour. Many are inexperienced computer users. Therefore, the SPSE should be built in such a way that the underlying technologies can be exploited by these people without a specialised knowledge of available software and hardware. This can only be achieved if the user's interaction with the data and associated features is apparent. Unfortunately, in reality the situation is far from ideal. To interact with scientific data, users often need to know specific definition languages, be able to run advanced simulation and visualisation routines and utilise software libraries and modules.

Even though the importance of user interaction has been realised by the SPSE community [14,18], related research in the field is still focused on technological issues of interactiveness. As for usability aspects of interaction, they have not been sufficiently addressed yet. Both commercial SPSEs and scientific prototypes suffer from usability problems.

The MathWorks MATLAB (http://www.mathworks.com/) is a technical computing environment for numerical computations and visualisations. It supports the data analysis process, starting from acquiring data from external devices and databases, through preprocessing, visualisation and numerical analysis, up to producing presentation-quality output. To enable experts to create their domain specific applications, MATLAB handles a wide variety of interactive tools and command-line based functionality [10]. As a result, getting acquainted with this SPSE normally takes a sufficient amount of time.

The Environmental Decision Support System has been developed at the North Carolina Supercomputing Center for assisting in design and modelling of diverse issues and scales. To model a process, a user first needs to choose simulation variables from a specifically formatted data file and then to link manually input and output of several programs provided by this SPSE. Both procedures require certain expertise from users and can be very time consuming. For instance, according to Fine et al [13], a simple air quality study can involve hundreds of program links and variable settings.

Also, many SPSEs are built as distributed infrastructures providing users with remote access to the data, analysis tools, visualisation and computational resources. This makes an SPSE a multi-user system.

The SPSE users divert with regard to their tasks and goals, knowledge and expertise, perceptual and cognitive abilities. Diversity inside a group of users having their individual abilities, interests and needs is a challenge for the SPSE community.

This paper considers an adaptive user interface as an opportunity in addressing this challenge. If an SPSE is able to adapt to users' knowledge and skills, tasks and preferences, abilities and disabilities, the efficiency of the user interaction can improve significantly, as well as coverage, reliability and usability of an SPSE in general.

We focus on the user model based interface adaptation. The user model plays the role of an adaptation criterion. It consists of human factors guiding and controlling the adaptation process. In this research, we have evaluated the influence of selected human factors on different types of interface adjustments performed manually by users of an SPSE. The statistical analysis of experimental data based on the Yule's coefficient of colligation [4] has indicated several dependencies. The experiment has been carried within the Knowledge Engineer's Workbench (KEW). KEW is an SPSE for knowledge acquisition and structuring, which permits the recording of interface adjustments. In total, seven human factors from the Wagner's Ergonomic Model [41] have been investigated.

The paper outlines the main findings of this research and is organised as follows. It starts with the overview of related work in the field of adaptive user interfaces provided in Sect. 2. In Sect. 3, an approach to the user model based interface adaptation of an SPSE is introduced. The main human factors from the Wagner's Ergonomic User Model are reviewed in Sect. 4. Sect. 5 presents the user study including the detailed design description, apparatus and study procedure. In Sect. 6, results of the statistical analysis of experimental data are discussed. The Intelligent System for User Modelling developed to provide automatic means of adaptation for the set of selected human factors is introduced in Sect. 7. The paper concludes with the discussion of design guidelines and plans for future work.

2 Related work

From related literature, we know two SPSEs referred to as adaptive: the Adaptive Distributed Virtual Computing Environment [21] and the Problem Solving Environment for Adaptive Engineering Computations [28]. However, in both cases the adaptation mechanism deals with the dynamic configuration of the application depending on available resources. As for adaptive user interfaces, even though this field has been an active research area for over 10 years, to our knowledge, this solution has never been applied to any existing PSE/SPSE.

Adaptive user interfaces allow the interactive environment to automatically learn and adapt to important user, task and environmental parameters. The most attention to the topic of adaptive interfaces has been gained in Web applications [1] and information systems [20]. Also, adaptive user interfaces have shown their promise (supported by experimental studies) in several application areas including recommendation and e-learning systems, content based, social and collaborative information filtering [19, 38].

All adaptive interfaces generate user profiles: sets of user categories defined by the values of variables. Variables from user profiles are the criteria used by the system to trigger and define the adaptation. These variables can be related to the behaviour of the user [35], the user's internal physiological state [16], user goals [30], knowledge [15] and personality [27].

According to Rothrock et al [33], existing adaptive user interface designs and models can be classified based on three major points of view: human factors, human–computer interaction and hybrid.

The human factors practioneers use a wide range of possible inputs about the user's behaviour and psychological state, such as task performance, eye tracking, EEG and even heart rate variability. Among the most important goals of these adaptive user interfaces is to take into account people's perceptual or physical impairments so that to allow them using a system with the minimal errors and frustration [42]. The Closed Loop Adaptive System [43] can serve as an example of the human factors based approach. In this system, the automation switch is controlled by a set of decision rules.

The human–computer interaction approach to adaptive interface design is based on a table of variables which categorises the users' goals and preferences. The user profile is inferred by analysing the user's behaviour, which is mostly restricted to the records of the user's action on the keyboard, mouse or other available input devices. A standard framework for the development of this type of adaptive user interfaces is described by Benyon [2].

Hybrid adaptive interfaces incorporate both the user-centred focus of the human factors approach with the system-oriented view of the human–computer interaction approach. For instance, Brusilovsky and Su [5] decompose an adaptive system into two processes. The first process models the user, while the second one relies on the generated user model to provide the basis for adaptation.

3 The user model based interface adaptation of an SPSE

The possible architecture of an adaptive SPSE is shown in Fig. 1. It supports the hybrid design approach from Brusilovsky and Su [5] and is formed by three major components: a problem solving framework, an adaptation engine and a data repository.

3.1 Problem solving framework

A problem solving framework is a combination of tightly coupled simulation, visualisation and user interaction tools.

An SPSE can be static or dynamic [18]. A static SPSE deals with time-independent data. Generated once, this data does not change. If an SPSE is dynamic, the interaction between simulation and visualisation compounds is more complicated. Simulated data is generated periodically and visualisations are updated with the same frequency. So, the user always deals with the graphical representation of the simulated data generated at the given time moment.

To observe better the graphical representation of scientific data, visualisation parameters can be modified by a user. Also, the user can monitor simulation routines and control the simulation parameters. In some SPSEs, simulation parameters can be changed by applying methods of interactive visualisation [45]. For instance, in a Virtual Radiology Explorer developed at the University of Amsterdam, the user can draw a connection or add a spline object to mimic the surgical operation [44].

3.2 Adaptation engine

An adaptation engine consists of three major compounds: a user model generator, a provider of the adaptation effect and a knowledge base.

A user model guides and controls the adaptation process. User modelling has proven to be very useful for applications, where a quick assessment of the user's background and knowledge is required [39].

A user model of an SPSE is an abstract representation of the relevant properties of the user. It can include such human factors as the users' task-related preferences

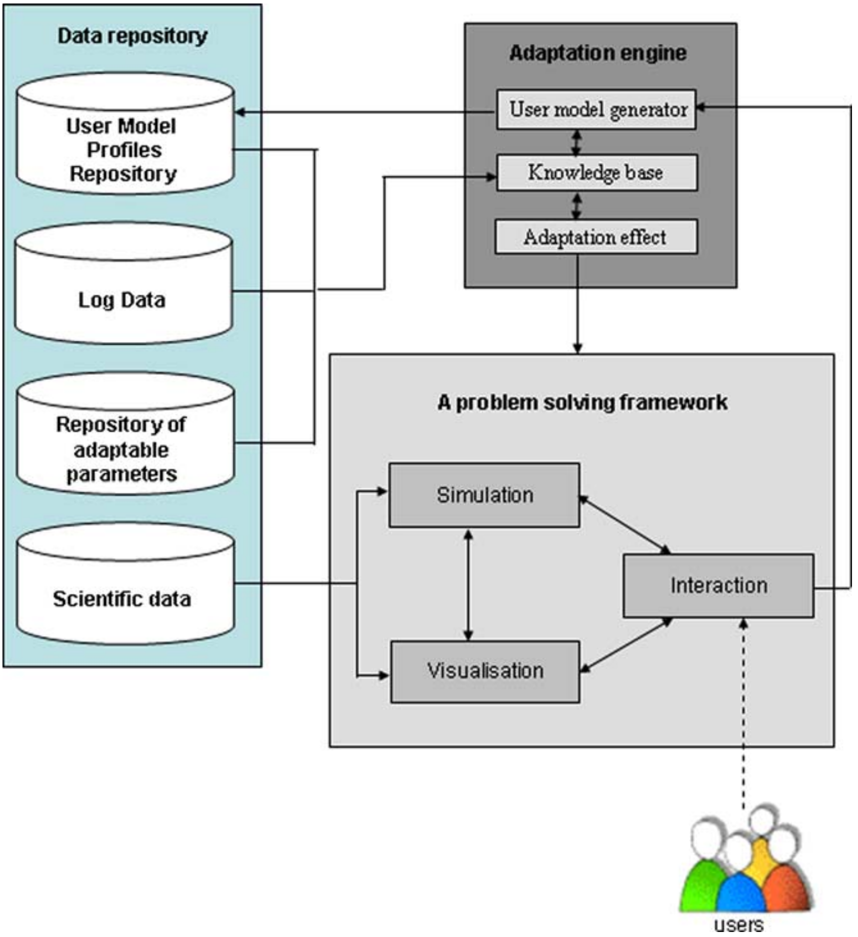


Fig. 1 A possible architecture of an adaptive SPSE

for data visualisations, experience with available simulation and decision support tools and individual psychological and cognitive characteristics.

A user model generator deals with the initialisation and update of a user model. The user model is open and can be modified if necessary, e.g. if a new adjustable interface element has been added. This allows to broaden the adaptability of an SPSE without the necessity to restructure the complete adaptation mechanism.

A user model generator also assigns profiles (values of variables from the user model [32]) serving for the identification of users. It collects relevant data about a user and saves it in a corresponding profile.

A provider of the adaptation effect is responsible for the correct configuration of a user interface based on the user model. Ideally, every user of an adaptive SPSE should be provided with an interface that suits him or her the best. This can be achieved by assigning individual user accounts (individual interface adaptation [47]). Each account corresponds to a user profile configured by a user model generator. Or, accounts can be also assigned to groups of the SPSE users (stereotype interface adaptation [47]), e.g. beginners, intermediate users, experts, etc.

The adaptation rules define how the user model attributes are used for performing the adaptation effect. These rules are stored in a knowledge base of an adaptive SPSE.

We base the process of adaptation on the notion of matching between user profiles and available interface configurations. Matching relationships are represented by the adaptation rules.

The intuitive semantics of an adaptation rule is as follows: if a user has profile P_r, then generate the configuration C_j. For instance, rules may link interface adjustments with a corresponding user profile or a set of profiles.

Hence, when a user profile has been created or updated by a user model generator, a provider of the adaptation effect starts searching among the adaptation rules stored in a knowledge base to find the match. If the match is found, the corresponding interface configuration will be loaded. Otherwise, no changes will be applied or the default user interface will be configured.

The adaptation rules are orthogonal to the user interface, which means that these rules are not embedded in the user interface code. For instance, they can be collected as supplementary files, which are consulted by run-time libraries utilised in the development of the SPSE user interface.

This requires the user interface to support an explicit model of the adaptable constituents determined by these rules – adaptable interface parameters.

3.3 Adaptable interface parameters

Interface parameters are elements of the human–computer interaction process that can be tuned or adjusted either manually by a user or automatically by a computer system [22]. The interface parameters that can be adjusted automatically by applying the rule based adaptation mechanism are also called adaptable interface parameters [8, 26].

To support adaptability, the knowledge about adaptable interface parameters is required. This knowledge allows a generator of the adaptation effect to properly instantiate an abstract physical interaction object into a concrete interaction object.

The adaptable interface parameters of an SPSE form three major groups:

- functional interface parameters;
- user support interface parameters;
- layout interface parameters.

Functional interface parameters [11] are very closely related to the functionality of an SPSE. They may include access settings, system vocabulary, available data representation forms and formats. For instance, certain working processes (simulation, visualisation, configuration routines) can be hidden from the user if his/her knowledge and expertise are insufficient to work with. Also, active controls and menu items can be customised in accordance with the users' experience and preferences. If the verbal component is important, the linguistic environment of an SPSE can be tuned. This adaptation deals with the vocabulary and morphological structures specific to the problem domain [40].

The efficiency of an SPSE depends to a great extent on the level of user support. User support [7] includes reference information and system feedback. Feedback closes the communication loop between the computer and the user, telling the user that his/her actions have been processed and what the results of those actions are. Invocations of error identifying routines clearly explain the user's mistakes. In the absence of error messages, normal feedback lets the user know that the system is behaving in expected manner. To ensure a good experience, instructions, error notifications, reference information and feedback generated by an SPSE need to be adapted in accordance with knowledge, experience and vocabulary of the current user.

Layout interface parameters characterise the customisation of an active workspace [17]. They may include size and appearance of menu items and toolbars, location and orientation of visualised objects, preferred forms for data representation, colour palettes, lighting effects, etc. An adaptive interface of an SPSE can remember adjustments of the interface layout parameters made manually by a user by tracing the user behaviour. Then, when the user logs in to an SPSE next time, he/she will be provided with exactly the same workspace as during the previous session.

The information about possible adjustments of interface parameters can be stored separately, for instance, in the data repository shown in Fig. 1. The SPSE data repository may also contain the user model and profile information, log-data of user–computer interactions, scientific data, etc. The log-data is important for monitoring the user behaviour and preferences. Scientific data is used for conducting experiments.

4 Human factors

Human factors are individual user characteristics that reflect the relationship between a human and the computer environment. The human factor engineering is the application of knowledge about human capabilities and limitations to a system or equipment design and development to achieve efficient, effective and safe system performance at minimum cost and manpower, skill and training demands [29].

4.1 The Wagner's Ergonomic Model

There have been several attempts made to classify human factors [37, 40, 41]. In this respect, the Wagner's Ergonomic Model [41] is the most extensive one. The model consists of 25 groups of 87 human factors.

The fragment of the Wagner's Ergonomic Model shown in Fig. 2 contains 18 human factors combined in seven groups. Each group has different impact on the process of human–computer interaction and its adaptation:

1. Demographic factors (age, gender) do not have direct influence on the process of human–computer interaction. However, they are widely used for the assessment of psychological, psychomotor and cognitive factors and therefore might have indirect impact [43].
2. Psychological communicative factors (locus of control, learning abilities) comprise the problems of clarity, understanding, usability and handiness [23]. Also, the consideration of these factors helps to reflect 'human-to-human' aspects of interaction [24] on the area of human–computer interaction.
3. To minimise the users' physical and mental discomfort of working with a computer system, human psychomotor abilities (attention focus, stress factors) need to be taken into account. Psychomotor is very important as it works hand

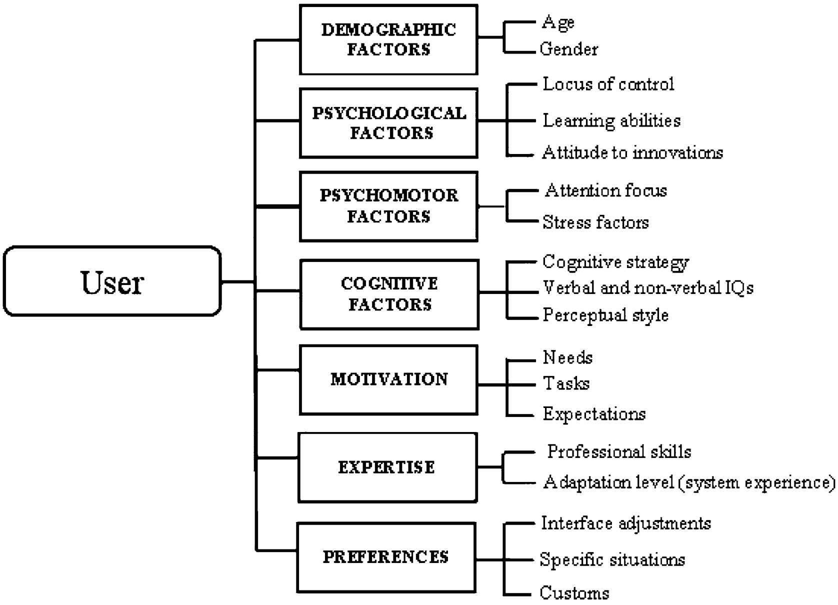


Fig. 2 Fragment of the Wagner's Ergonomic Model (adapted from Wagner [41])

in hand with cognitive thinking. It requires skills physical in nature. Mandel [22] describes human's psychomotor abilities as "coordinated muscular movements that are typified by smoothness and precise timing". For instance, psychomotor factors can help to define when it is necessary to provide the user with additional support or control.

4. Cognitive factors (perceptual style, cognitive strategy) are related to the deep problems of human mind and memory. One of the most important factors of efficient communication and learning is the coincidence of the cognitive features of the interacting beings [12]. This factor group gives the opportunity to overcome the cognitive dissonance between the user's expectations and the environmental behaviour and layout.
5. By taking into account motivation factors (tasks, expectations), it is possible to simplify the work of a user and to speed-up the interaction process, e.g. by providing a motivated working environment.
6. Expertise factors (skills, adaptation level) characterise the user's experience and understanding of the problem to be solved. Many factors from this group may evolve over time [26]. When the expertise factors are used as the adaptation criteria, both the user's performance and the system robustness can be improved, e.g. if support and privileges are assigned to users based on their knowledge and expertise.
7. Preferences (interface adjustments, specific situations) are usually traced by recording the user behaviourial data [2]. This allows the customisation of the working environment, e.g. by reproducing interface adjustments done manually by a user.

The rest of the Wagner's Ergonomic Model deals mostly with the ergonomic conditions of the workspace and has very little relevance to human–

computer interaction. The complete version of the model can be found in Wagner [41].

4.2 The motivation of an experimental study

Today's choice of human factors as adaptation criteria depends to a great extent on the application domain of an adaptive system. Among factors most commonly utilised as user variables are those related to people's expertise, motivation and preferences. As for individual human abilities (perceptual and cognitive) and personal user characteristics (psychological and demographic), they have been rarely applied as adaptation criteria. And the main reason for this is uncertainty about their influence on people's preferences for different interface configurations.

Indeed, if users are computer experts, it is very difficult to evaluate the influence of their individual abilities on the way these people interact with a system. Their computer skills and experience are dominant factors. However, if users are non-computer experts, their expertise is not sufficient enough to predetermine interface preferences and therefore the impact of the users' individual diversity will increase.

The SPSE users are domain experts investigating scientific phenomena. Since the majority of them are non-computer experts, an SPSE provides nice opportunities for performing an experimental study aimed at investigating existing dependencies between personal user characteristics and people's preferences for different interface adjustments. Moreover, the problem solving process depends heavily on people's cognitive and perceptual abilities [34], which can potentially increase the impact of these factors.

Having this in mind, we selected seven human factors from the Wagner's Ergonomics Model to evaluate their impact on interface adjustments made manually by users during the problem solving process. The motivation for choosing each factor is explained below.

- Gender (demographic factor)
  It has been decided to evaluate the impact of this factor because it plays an important role in the assessment of people's leaning abilities, locus of control and attention focus introduced further.
- Learning abilities (psychological factor)
  This factor characterises the users' abilities of adapting to new situations. Thus, people with the low "learning abilities" factor prefer to be told or shown how to deal with a new situation. On the contrary, people with highly developed learning abilities enjoy the hands-on approach much more than detailed instructions [9]. People having different learning abilities require different support from an SPSE. Also, people with low learning abilities are strongly affected by inconsistencies related to functionality, vocabulary or user interface design of an SPSE. Therefore, this factor may potentially influence users' preferences for adjustments applied to functional and user support interface parameters.
- Locus of control (psychological factor)
  This factor permits to assess the extent to which an individual possesses internal or external reinforcement beliefs [27]. The evaluation of the locus of con-

trol can help to indicate what level of help instructions the current user should be provided with. Internals prefer to play an active role in the user–computer interaction. Command-line based dialogue, advanced help search, etc. are potentially good options for this user type. On the contrary, externals are very much dependent on the opinion of others. While interacting with a computer, they would like to receive confirmations of correctness/incorrectness of their actions and therefore will probably require an additional guidance from an SPSE.

- Attention focus (psychomotor factor)
  This human factor deals with the attention allocation and switching behavior of users [34]. Every human can be characterised by a limited time interval, when his/her performance is the most efficient and the number of mistakes is minimal. Users with the low "attention focus" factor will benefit from extra support and control over their activities provided by an SPSE, especially if they need to perform destructive operations. Also, abilities to switch between tasks are not the same for all people. Some users will be able to easily deal with several active working spaces simultaneously. Others would prefer to focus on one task only. The last will require from an SPSE sequential support of their activities. This implies that the factor "attention focus" may potentially affect people's choice for manual adjustments of user support and layout interface parameters of an SPSE.
- Cognitive strategy (cognitive factor)
  Everybody has his/her own particular way of working and thinking. For instance, in their reasoning, people usually follow inductive or deductive cognitive style or strategy [12]. Those who adhere to deduction perform their cognitive activity with the top-down strategy from the higher level of abstraction to more and more detailed schema. And vice versa, inductive people ascend from unconnected elementary concepts to meta-concepts. The factor "cognitive strategy" definitely influences people's preferences for the organisation of the reference information ('top-down', 'bottom-up'). Also, this factor may affect layout interface parameters, especially with regard to the data mining and interactive visualisation tools of an SPSE.
- Verbal and nonverbal IQs (cognitive factors)
  The functional asymmetry of the cerebral hemispheres results in two forms of thinking: logical (verbal) related to the left hemisphere and creative (nonverbal) that originates in the right one [24]. People, whose nonverbal IQ is higher than verbal, are right-thinking. Right-thinking users prefer to deal with graphical information rather than with the text. On the contrary, left-thinking, whose verbal IQ is higher than nonverbal, will process the same information much faster if it is represented in a written or spoken form. So, the ratio between verbal and nonverbal IQs can potentially define the user's preferences for forms and formats of data representation, interface layout and user support features provided by an SPSE.

5 Experimental setup

The goal of this experimental study was to check which of the human factors selected earlier have the most impact on people's preferences for manual interface adjustments and therefore can potentially be applied as the adaptation criteria to the SPSE user interface.

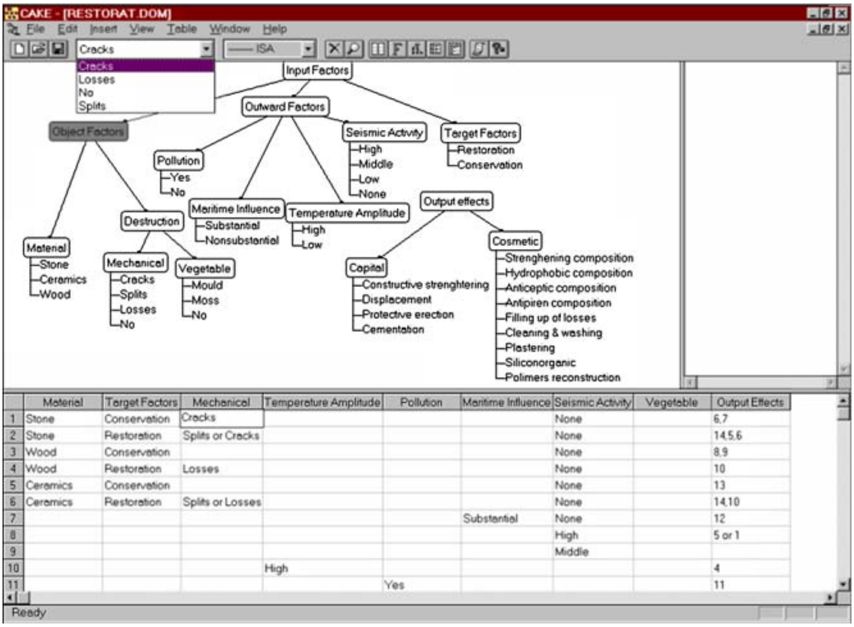
The major part of the experiment has been carried within the Knowledge Engineer's Workbench, which allows recording of interface adjustments. For the evaluation of human factors, the testing component of the Intelligent System for User Modelling [46] has been used.

5.1 The knowledge Engineer's Workbench

The Knowledge Engineer's Workbench (KEW) is an SPSE for the knowledge acquisition and structuring. It combines tools for performing the conceptual analysis of scientific data when the stages of problem identification and knowledge extraction are passed (see Fig. 3 for a screenshot). Conceptual analysis and knowledge structuring are among the most important stages of the knowledge acquisition process. And there is no doubt that they form the most intellectual part of this procedure. Also, KEW allows the direct accumulation of knowledge obtained from domain experts by translating this knowledge into rules, frames and other textual descriptions. More information about the KEW functionality can be found in refs. [12, 45].

The KEW interface parameters and their possible adjustments are summarised in Table 1. In total, five interface parameters can be adjusted.

- Access to working processes (functional interface parameter)
  Working processes are available computational routines of an SPSE. Normally, they are hidden from a user and can be activated by selecting the menu item



	Material	Target Factors	Mechanical	Temperature Amplitude	Pollution	Maritime Influence	Seismic Activity	Vegetable	Output Effects
1	Stone	Conservation	Cracks				None		6,7
2	Stone	Restoration	Splits or Cracks				None		14,5,6
3	Wood	Conservation					None		8,9
4	Wood	Restoration	Losses				None		10
5	Ceramics	Conservation					None		13
6	Ceramics	Restoration	Splits or Losses				None		14,10
7						Substantial	None		12
8							High		5 or 1
9							Middle		
10				High					4
11					Yes				11

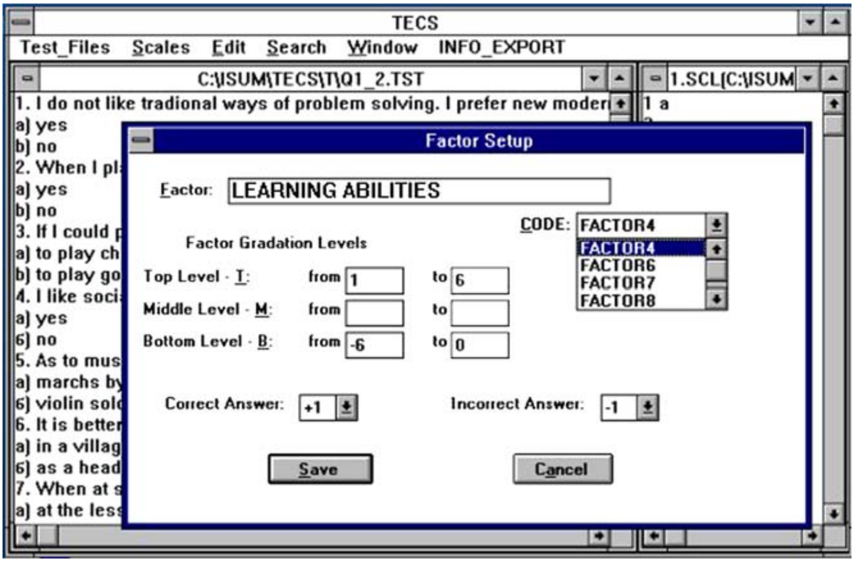
Fig. 3 The Knowledge Engineer's Workbench: knowledge structuring tools

Table 1 Adjustable interface parameters of the KEW system

Interface parameter	Type	Number	Possible adjustments (reference number: description)
Access to working processes	Functional	FP1	FP1-1: unlimited FP1-2: motivated FP1-3: minimal
Type of dialogue	Functional	FP2	FP2-1: passive FP2-2: mixed FP2-3: active
Level of help instructions	User support	SP1	SP1-1: minimal SP1-2: content-oriented SP1-3: maximal
Data representation form	Layout	LP1	LP1-1: textual LP1-2: graphical LP1-3: combined
Colour palette	Layout	LP2	LP2-1: default LP2-2: adjusted

or typing in a certain command. The functional interface parameter "access to working processes" permits to limit the users' access to the functionality of an SPSE. In the KEW system, three different levels for the adjustment of this parameter are available: unlimited (all KEW working processes are available), motivated (all working processes related to knowledge structuring are available) and minimal (the limited set of working processes is available).

– Type of dialogue (functional interface parameter)
  This parameter defines the user's activeness/passiveness during the human–computer interaction process [11]. A command-line based dialogue is an active type of dialogue because the user always plays the leading role. Q&A prompts, menus, screen forms are elements of a passive dialogue because the user plays the role of a follower guided by a system. Also, sometimes a computer system can support both passive and active types of dialogue. This is so-called mixed dialogue. According to this classification, KEW provides with a choice of passive (menus and fill-in forms), active (command-line based) and mixed dialogue types.
– Level of help instructions (user support interface parameter)
  Help instructions include reference information provided on demand of the user and system feedback. KEW supports three different levels of help instructions: minimal support (limited reference information is provided), maximal support (detailed help instructions and prompts are provided) and content-oriented. The content-oriented level of support allows a user to structure the reference information based on specific keywords.
– Form of data representation (layout interface parameter)
  This parameter is responsible for the representation of the system output. The KEW system supports the following forms of data representation: textual, graphical and combined (text and graphics). Format-related adjustments have not been considered.
– Colour palette (layout interface parameter)



1. I do not like tradional ways of problem solving. I prefer new moder
a) yes
b) no
2. When I pl
a) yes
b) no
3. If I could p
a) to play ch
b) to play go
4. I like soci
a) yes
6) no
5. As to mus
a) marchs by
6) violin sold
6. It is better
a) in a villag
6) as a head
7. When at s
a) at the less

1 a

Factor: LEARNING ABILITIES

CODE: FACTOR4
FACTOR4
FACTOR6
FACTOR7
FACTOR8

Factor Gradation Levels
Top Level - T: from 1 to 6
Middle Level - M: from to
Bottom Level - B: from -6 to 0

Correct Answer: +1
Incorrect Answer: -1

Fig. 4 The test composition environment

The user of the KEW system is allowed to customise the default colour palette (background, text, drawings, error notifications, etc.). KEW can recognise if the adjustment of the default colour palette has been made.

KEW allows recording data about the interface adjustments done manually. The component of tracing the user behaviour stores the information about all interface adjustments made by a user in a corresponding log-file [45].

5.2 Evaluation of human factors

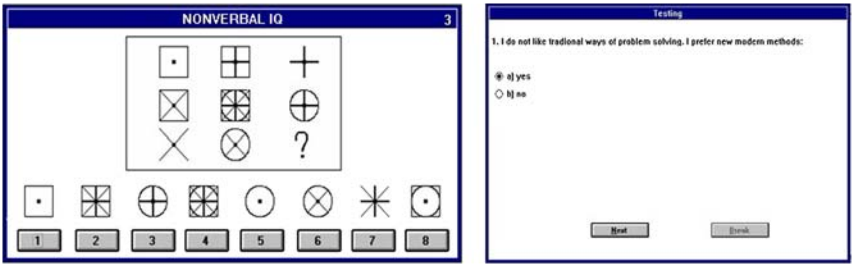
To organise the computer based evaluation of human factors, the Test Creating Shell (TECS) has been used. TECS is part of the Intelligent System for User Modelling [46]. It provides a rich set of tools for the creation and modification of tests, scales and factor descriptors.

Each test is always associated with at least one scale. The deletion of a test results in the deletion of all scales associated with this test. Each scale is provided with the factor information. The factor information includes factor description (name, unique code, etc.), factor gradation levels and weights of correct/incorrect answers.

Figure 4 illustrates the composition of a Q&A test for the evaluation of the factor “learning abilities”.

The experimental data is interpreted based on three linguistic variables “T”, “M” and “B”. We split the set of basic values of each factor into three subsets: T_k, M_k, B_k. T_k specifies high factor values of the kth factor; B_k specifies low factor values; M_k – middle range values. M_k can be an empty subset as shown in Fig. 4.

Each linguistic variable corresponds to a specific subset: “T”$\rightarrow T_k$, “M”$\rightarrow M_k$ and “B”$\rightarrow B_k$. For instance, linguistic variable “T” will be assigned if the basic



1. I do not like tradional ways of problem solving. I prefer new modern methods:

● a] yes
○ b] no

Fig. 5 Evaluations (fragments) of human factors: *left:* “nonverbal-IQ” based on the Raven’s test for nonverbal intelligence [31]; *right:* “learning abilities” based on the Cattel’s 16PF personality test [6]

value of the kth factor $y_k \in T_k$. If $y_k \in B_k$, variable “B” will be assigned. Otherwise, if $y_k \in M_k \wedge M_k \neq 0$, it will be variable “M”.

TECS allows the composition of both questionnaire and game-based tests (Fig. 5). In this experiment, game testing has been applied to the evaluation of the human factors “verbal and nonverbal IQs”, “cognitive strategy” and “attention focus”. The rest of the factors have been evaluated based on questionnaire forms.

5.3 Participants

Fifty-four subjects (23 female, 31 male) participated in the experiment. All subjects were undergraduate MS students attending the project-course “Expert Systems”. At the end of the course, students were expected to develop a knowledge base for the domain of interest using the KEW system.

All subjects had extensive experience with computer systems, but none reported familiarity with adaptive applications or knowledge acquisition systems such as KEW. During the introduction session, they have been explained how to use conceptual and structuring tools provided by KEW and how to adjust manually the GUI of the system to make the interaction more comfortable. Thanks to individual accounts, the information about interface adjustments made by each subject was collected repeatedly during every lab session. Each subject spent at least 32 h working with the KEW environment: 4 h per week, 8 weeks in total. The last saved interface configurations have been processed.

To evaluate individual abilities of subjects (human factors described in Sect. 4.2), subjects also participated in a single 1.5–2 h computer testing session. The factors evaluation was performed prior to the actual experimental study carried within the KEW system.

5.4 Analysis

To analyse the quantitative data, we used the Yule’s coefficient of colligation [3]. The Yule’s coefficient of colligation is the function of two variables. It provides the information about their interrelation within the defined diapason of basic values.

Traditionally, for the analysis of dependences between random variables, the coefficient of correlation [36] is applied. However, when joint density function is estimated, it is more efficient to use the Yule's coefficient of colligation.

The Yule's coefficient of colligation $\mathrm{C}_{F(x,y)}$ characterising interrelation between two random variables x and y can be formulated as follows:

$$C_{F(x,y)} = \frac{f(x,y)}{f(f)f(y)},$$

where $f(x, y)$ is the joint distribution density,

$$\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)dxdy = 1$$

$f(x)$, $f(y)$—marginal distribution densities

$$f(x) = \int_{-\infty}^{+\infty} f(x,y)dy,\ f(y) = \int_{-\infty}^{+\infty} f(x,y)dx.$$

If the coefficient of colligation is equal to 1, the random variables are independent. Otherwise, they are considered dependent. The more coefficients of colligation deviate from 1, the more significant pair dependence is.

Conditional probabilities and Yule's coefficients of colligation calculated for each pair <interface parameter, human factor> can be found in the Appendix (Tables A1–A5). The graphical representation of the statistical data is provided in the next section.

6 Results

As can be seen in Fig. 6a, coefficients of colligation calculated for the pairs <"access to working processes", "learning abilities"> and <"access to working processes", "attention focus"> deviate significantly from 1. Thus, for the factor "learning abilities" $\mathrm{C}_{F\mathrm{max}} = 1.49$, $\mathrm{C}_{F\mathrm{min}} = 0.50$ and for the factor "attention focus" $\mathrm{C}_{F\mathrm{max}} = 1.65$, $\mathrm{C}_{F\mathrm{min}} = 0.46$. These relatively high deviations compared to other factors (see Tables A1 and A2 in the Appendix) indicate that individual learning and concentration abilities influence the choice of users for the adjustment of the KEW interface parameter "access to working processes".

For the parameter "type of dialogue", we were able to select three human factors for which coefficients of colligation deviate significantly from 1 (see Fig. 6b): "learning abilities" ($\mathrm{C}_{F\mathrm{max}} = 1.37$, $\mathrm{C}_{F\mathrm{min}} = 0.61$), "locus of control" ($\mathrm{C}_{F\mathrm{max}} = 1.44$, $\mathrm{C}_{F\mathrm{min}} = 0.55$) and "attention focus" ($\mathrm{C}_{F\mathrm{max}} = 1.57$, $\mathrm{C}_{F\mathrm{min}} = 0.45$).

Hence, our hypothesis about the influence of the factor "learning abilities" on people's preferences for the adjustments of functional interface parameters (formulated in Sect. 4.2) has been supported by the experimental data. Also, the discovered dependency between the parameter "type of dialogue" and the factor "locus of control" does not contradict our expectations about different needs

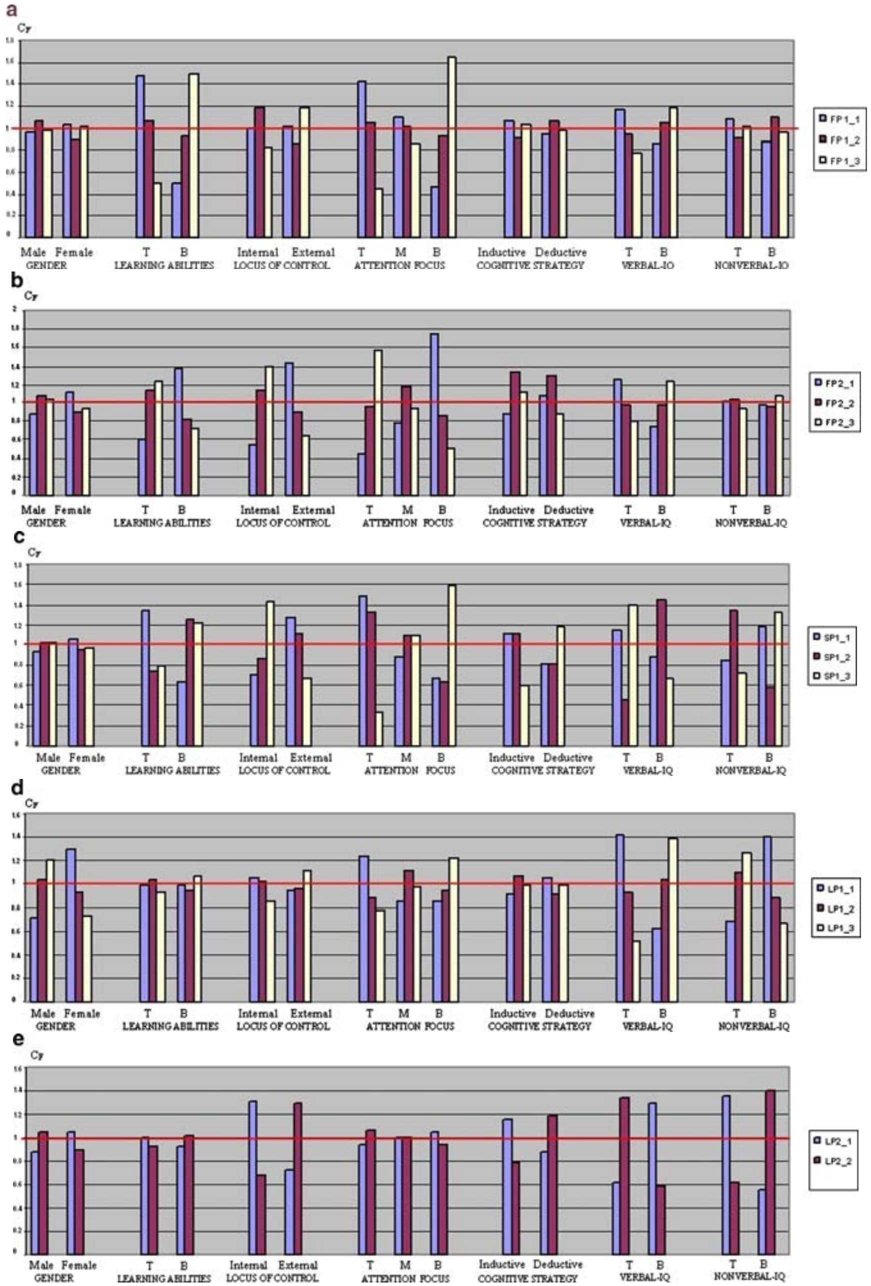


Fig. 6 Yule's coefficients of colligation calculated for the pairs **a** <"access to working processes", human factor > **b** <"type of dialogue", human factor> **c** <"level of help instructions", human factor> **d** <"data representation form", human factor> **e** <"colour palette", human factor>

of internal and external users in guidance and support provided by an SPSE. In addition, two unexpected dependencies have been found. According to Fig. 6a and b, adjustments of two functional interface parameters (“access to working processes” and “type of dialogue”) are affected by the concentration abilities of users.

The adjustment of the interface parameter “level of help instructions” is influenced the most by individual user characteristics (Fig. 6c). The coefficients of colligation calculated for five different human factors deviate from 1. As can be seen in Fig. 6c, “gender” is the only factor that does not have any impact on the adjustment of this interface parameter: $\mathrm{C}_{F\max} = 1.06$, $\mathrm{C}_{F\min} = 0.94$.

Overall, the experimental data does not contradict our hypotheses formulated in Sect. 4.2 about the influence of people’s psychological, psychomotor and cognitive abilities on adjustments of user support interface parameters. However, the hypothesis about the impact of the factor “cognitive strategy” has not been well supported experimentally. Except $\mathrm{C}_{F(\text{“SP1}-3\text{”},\text{“Deductive”})} = 0.66$, which deviates significantly from 1, other deviations of the coefficients of colligation calculated for the pair <“level of help instructions”, “cognitive strategy”> are very low (see Table A3 in the Appendix). The content-oriented level of support (SP1-3) has been hardly chosen by subjects as, they explained later, manual structuring of the reference information required additional time and effort.

According to Fig. 6d, three human factors have the most influence on the adjustment of the interface parameter “data representation form”: “verbal IQ” ($\mathrm{C}_{F\max} = 1.41$, $C_{F\min} = 0.52$), “nonverbal IQ” ($\mathrm{C}_{F\max} = 1.40$, $C_{F\min} = 0.67$) and “gender” ($\mathrm{C}_{F\max} = 1.29$, $C_{F\min} = 0.72$). As for the “colour palette” (Fig. 6e), coefficients of colligation calculated for the factors “locus control” ($\mathrm{C}_{F\max} = 1.31$, $\mathrm{C}_{F\min} = 0.68$) and “nonverbal IQ” ($\mathrm{C}_{F\max} = 1.40$, $\mathrm{C}_{F\min} = 0.55$) deviate significantly from 1.

Hence, our hypotheses about the influence of verbal and nonverbal IQs on people’s preferences for the adjustments of user support interface parameters have been supported by the experimental data. Unfortunately, the hypotheses about the impact of “attention focus” and “cognitive strategy” have not been supported (see Tables A5 and A6 in the Appendix).

Again, two unexpected dependencies have been found. The experimental data indicates that gender has an effect on people’s preferences for data representation forms (Fig. 6d). And, according to Fig. 6e, the factor “locus of control” affects the user’s choice between customised and non-customised interface layouts of an SPSE (colour palette in our experiment).

7 Intelligent System for User Modelling

To provide automatic means of adaptation for the set of selected human factors, we developed the Intelligent System for User Modelling (ISUM) [46].

7.1 System architecture

ISUM is an instrumental complex aimed at helping developers of adaptive SPSEs in design of the user model based adaptation mechanisms. The system architecture

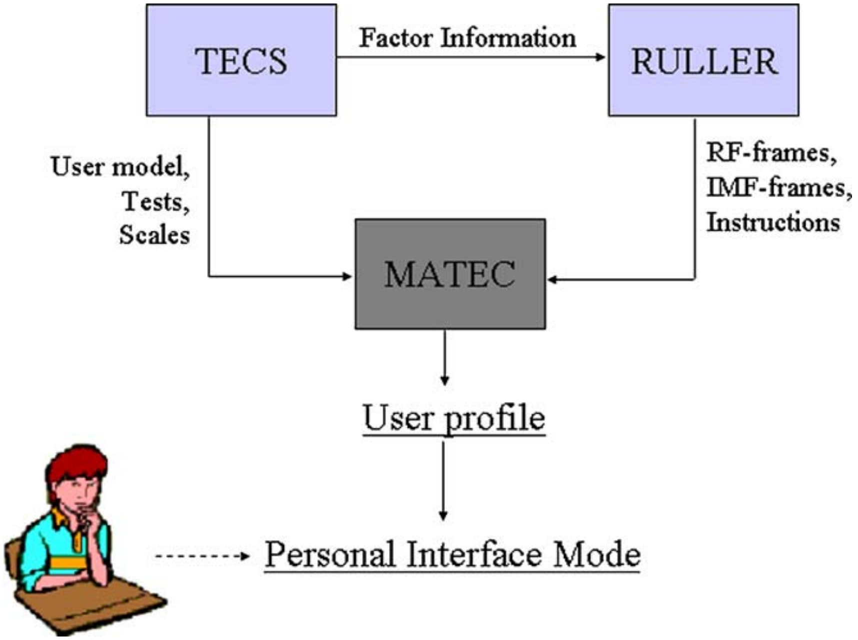


Fig. 7 The Intelligent System for User Modelling: architectural design and dataflow

and the dataflow among its main components are shown in Fig. 7. These components are as follows:

- Test Creating Shell (TECS)
  TECS functionality has been already introduced in Sect. 5.2 of this paper. As mentioned earlier, TECS allows to create and modify tests, scales and factor descriptors. A set of factors forms the user model of an SPSE.
- RULLER
  RULLER provides tools for the development of the SPSE knowledge base. It allows a developer to create the adaptation rules and to generate supplementary instructions for the users. Given the need for inheritance and defaults as well as the need of flexibility, we used the frame approach of knowledge representation [25].
- Main Testing Component (MATEC)
  MATEC is a component for direct user testing. At the end of a testing session, the current user is assigned with a Personal Interface Mode (interface configuration), which suits him/her the best. The interface configuration data is stored in a file associated with the user login information (log-file). Every time the same user logs in to an adaptive SPSE, this data is retrieved.

7.2 Knowledge representation

The interface adaptation is handled by condition action rules stored as frames in a knowledge base of an SPSE. Frames are structures representing knowledge. Like concepts, in many of the semantic network representations, frames are descriptions of objects. The descriptions in a frame are called slots [25].

RULLER allows two different types of frames to be created: Recognition Frames (RF) and Interface Mode Frames (IMF). RF frames define user profiles. IMF frames specify Personal Interface Modes.

In general, structures of RF and IMF frames can be represented as follows:

RF_k = {RFname(k),
<AKO: RFname(1)>
....
<AKO: RFname(k-1)>
<Code(f_1): value(f_1)>
<Code(f_2): value(f_2)>
....
<Code(f_μ): value(f_μ)>}

IMF_i = {IMFname(i),
<RF: RFname(k)>
....
<RF: RFname(j)>
<Code(Ipar_1): value (Ipar_1)>
<Code(Ipar_2): value (Ipar_2)>
....
<Code(Ipar_α): value (Ipar_α)>}

Each frame has a unique name: “RFname” for RF frames and “IMFname” for IMF frames. “RFname” and “IMFname” can also be names of files where the corresponding information is stored.

The number of slots in frames can vary. The RF slots contain information about factors (f_1, f_2, ... f_μ) from the user model of an SPSE. The description includes the unique factor code and the linguistic factor value. Linguistic variables “T”, “M” and “B” form the range of available values for each factor.

The IMF slots describe adjustments of adaptable interface parameters (Ipar_1, Ipar_2, ... Ipar_α). In a similar way, the description includes the unique code of an interface parameter and a value specifying the adjustment that has to be applied to this parameter.

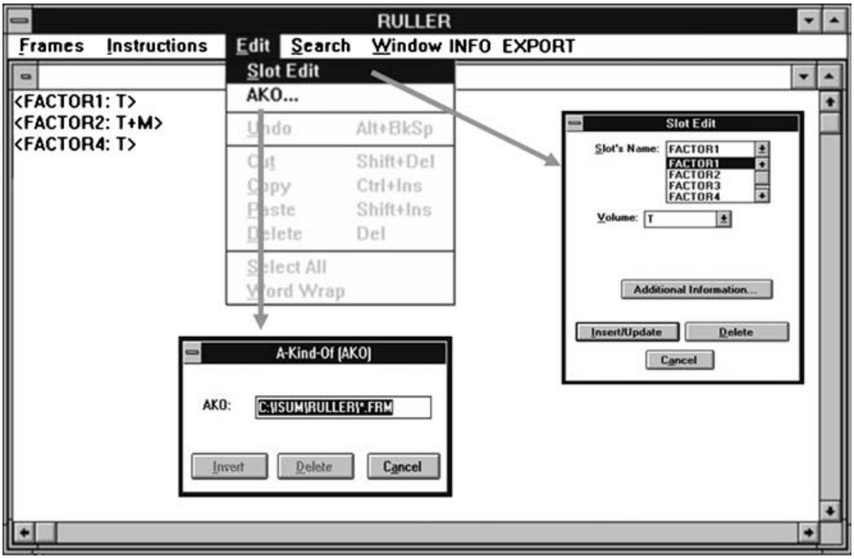
We use two types of relations to describe relationships between frames:

- AKO: This relation describes the hierarchical structure among the recognition frames. Each RF frame in the AKO chain inherits the factor attributes of all recognition frames above it and can introduce additional attributes. This allows new factors to be added to the user model of an SPSE without the need of complete restructuring of a knowledge base.
- RF: This relation describes connections between interface mode frames and recognition frames. This relation allows a transition from a user profile to a Personal Interface Mode. Each IMF frame can be connected with one or more recognition frames.

The process of editing RF frames is shown in Fig. 8. The factor information required for slot editing is provided by the TECS component. As soon as user modelling is finished, factor information can be transferred to other components of ISUM by selecting the “INFO_EXPORT” option from a top menu (see Fig. 4).

The IMF frame editor is shown in Fig. 9. At this moment, the adjustments of maximum six interface parameters can be specified. However, if required, the list of adaptable interface parameters can be expanded.

In addition to Personal Interface Modes specified via IMF frames, the Default Interface Mode can be configured. The Default Interface Mode will be assigned to the SPSE users whose profiles do not match any recognition frame from those stored in a knowledge base.



<FACTOR1: T>
<FACTOR2: T+M>
<FACTOR4: T>

Slot's Name: FACTOR1

Volume: T

AKO: C:\ISUM\RULLER*.FRM

Fig. 8 Tools for editing recognition frames

Similar to TECS, RULLER also has facilities to export data, which implies that the copy of a knowledge base will be stored at the specified location for the later utilisation by the testing component MATEC.

7.3 Dynamic generation of a Personal Interface Mode

MATEC is responsible for the generation of a Personal Interface Mode. This process comprises five following stages:

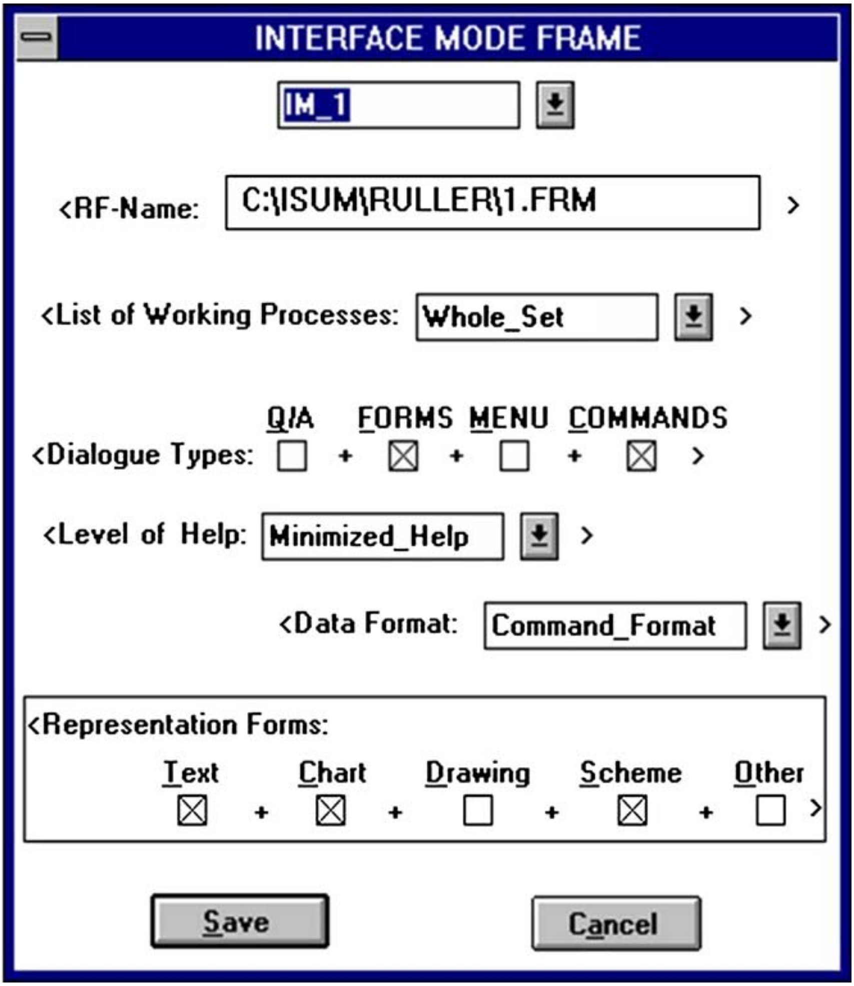
1. User testing;
2. Generation of a user profile;
3. Interpretation of a user profile;
4. Providing the user with a Personal Interface Mode specification;
5. Final check and editing of a specification by the user.

Most of the MATEC functionality is dependent on the data provided by other components of ISUM, i.e.: tests, scales and factor information arrive from TECS (stages 1–2); RF and IMF frames— from RULLER (stages 3–4).

During testing, the user's answers are validated based on the corresponding scale(s) provided for each test. Weights of correct/incorrect answers are used to calculate the digital value for each factor. Digital values are then interpreted via linguistic variables "T", "M" and "B" as described in Sect. 5.2. A combination of linguistic variables assigned to all factors from the user model forms a unique profile generated for the current user.

A Personal Interface Mode can be assigned to the user if his/her profile matches an RF frame stored in the SPSE knowledge base. Otherwise, the Default Interface Mode will be configured.

The procedure is as follows. Each factor from a user profile is compared to all RF slots with the same factor code. To match, a slot and a factor should have



INTERFACE MODE FRAME

IM_1

<RF-Name: C:\ISUM\RULLER\1.FRM >

<List of Working Processes: Whole_Set >

<Dialogue Types: Q/A ☐ + FORMS ☒ + MENU ☐ + COMMANDS ☒ >

<Level of Help: Minimized_Help >

<Data Format: Command_Format >

<Representation Forms: Text ☒ + Chart ☒ + Drawing ☐ + Scheme ☒ + Other ☐ >

Fig. 9 Editing of an Interface Mode Frame

the same linguistic value. It is important to mention that some slots may contain multiple values (e.g. “T + M” in Fig. 8) meaning that it will be sufficient if the linguistic variable assigned to the factor matches any of the values from the specified range (e.g. in case “T + M”, “T” and “M” are both true values).

If in a RF frame, all slots match factors from a generated user profile, the desired RF frame has been found. When the match is found, the RF frame’s name will be used as a criterion to retrieve the related IMF frame from a knowledge base.

To make sure that the Personal Interface Mode really matches the user’s expectations, we provide the SPSE users with a possibility to control manually the adaptation process. The user can check and edit the automatically configured interface mode before it is saved.

A Personal Interface Mode is not always unique. In principle, the same interface mode can be configured for people with different user profiles.

8 Discussion and conclusions

The goal of this study was to confirm experimentally that the role of individual human abilities is of major importance in the design of adaptive user interfaces for scientific problem solving environments (SPSEs).

An SPSE is a computer based framework aimed to facilitate the interactive exploration and analysis of scientific data. However, this aim is not easy achievable due to the diversity inside the prospective user group. The users vary with regard to their knowledge and experience, tasks and motivation, perceptual and cognitive abilities.

This challenge can be addressed by applying an adaptive user interface to the SPSE. Through the dynamic configuration of adjustable interface parameters, an adaptive user interface will allow more apparent and intuitive access to scientific data and associated features. In this research, we focused on the user model based interface adaptation. The user model of an SPSE is an abstract representation of the people's relevant properties. It consists of human factors, where each factor reflects the relationship between a human and an SPSE from a different perspective.

Traditionally, people's preferences, motivation and experience are among the most commonly utilised user-related variables in adaptive interface design. As for individual human abilities, they have been rarely applied to the adaptive user interaction. Meanwhile, taking into account personal user characteristics is essentially important, especially if an adaptive system is oriented to non-computer experts.

The prospective users of the SPSE are domain experts, scientists investigating phenomena and trying to predict their behaviour. Usually their knowledge and expertise with IT technology are very limited. In addition, problem solving process depends heavily on cognitive and perceptual user characteristics.

Having this in mind, we performed a series of experiments aimed to investigate dependencies between individual human abilities and people's preferences for the adjustments of the SPSE user interface. Experiments have been carried within the KEW system. KEW is an SPSE for knowledge acquisition and structuring. It allows a user to adjust manually five interface parameters and records the corresponding information about adjustments made in a log-file.

Seven human factors from the Wagner's Ergonomic Model have been chosen for evaluations. A hypothesis about the potential impact of each human factor on the adaptation process has been formulated and validated experimentally. Both the questionnaire and game based computer testing have been applied. To perform the statistical analysis of quantitative data, the Yule's coefficient of colligation has been used.

Overall, the experimental data shows that individual human abilities affect people's choice for interface adjustments. The majority of hypotheses formulated prior to experiments have been well supported by experimental data. However, some unexpected dependencies have been also found. Table 2 summarises all discovered dependencies between selected human factors and adjustable interface parameters of the KEW system. Human factors are grouped in accordance with their influence on different interface parameters.

From seven human factors, "learning abilities" and "attention focus" have the most impact on the adaptation process. "Verbal and nonverbal IQs" also appeared

Table 2 Discovered dependencies inside pairs <interface parameter, human factor>

Interface parameters	Human factor
Access to working processes (functional)	Learning abilities (psychological) Attention focus (psychomotor)
Type of dialogue (functional)	Learning abilities (psychological) Locus of control (psychological) Attention focus (psychomotor)
Level of help instructions (user support)	Learning abilities (psychological) Locus of control (psychological) Attention focus (psychomotor) Cognitive strategy (cognitive) Verbal IQ (cognitive) Nonverbal IQ (cognitive)
Data representation form (layout)	Gender (demographic) Verbal IQ (cognitive) Nonverbal IQ (cognitive)
Colour palette (layout)	Locus of control (psychological) Nonverbal IQ (cognitive)

to be important, especially for SPSEs that support different forms and formats of data representation.

Dependencies provided in Table 2 can serve as criteria for the inclusion of human factors into the user model of an adaptive SPSE. The diversity in the influence of selected human factors indicates that their applicability as adaptation criteria will depend on adaptable interface parameters supported by the SPSE. For instance, functional and user support interface parameters will be affected by psychological and psychomotor factors the most. As for cognitive factors, they will have an effect on the user support and interface layout.

To automatically generate personal interface configurations based on the individual abilities of SPSE users, we developed the Intelligent System for User Modelling (ISUM). The system provides tools for building the testing component of an adaptive SPSE and acquisition and structuring tools for the development of the SPSE knowledge base. The frame approach has been chosen to represent the adaptation rules.

Table 2 is certainly not argued to be complete. Future research is hoped to expand and provide more insight into the adaptation criteria so that a concise set of guidelines can be developed.

However, some findings presented in this paper have been already successfully applied to the KEW system. The dynamic configuration of the KEW interface parameters is currently guided by four human factors: “learning abilities”, “attention focus”, “verbal and nonverbal IQs”. A small observational study performed recently indicated shortening of the introduction period for novice users and the decrease of data-entry mistakes. Also, the users’ satisfaction from human–computer interaction raised after the adaptation was applied [45].

As a next step, we are going to investigate possibilities for applying an adaptive user interface to a multi-modal SPSE. A multi-modal SPSE provides a user with a choice of input/output devices and display systems. This type of an SPSE is of specific interest to us because it allows users to switch between desktop, virtual and mixed realities [44]. The interactive image based exploration of vascular disorders will serve as the case study for the further research.

Appendix: statistical evaluation of experimental data

Table A1 Conditional probabilities $P(x, y)$ and Yule's coefficients of colligation $C_{F(x,y)}$ calculated for the interface parameter "access to working processes"

Human factor[a]	Linguistic variable	Adjustments of the interface parameter FP1 "access to working processes"					
		FP1-1		FP1-2		FP1-3	
		$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$
Gender	Male	0.29	0.96	0.15	1.07	0.10	0.97
	Female	0.27	1.03	0.11	0.90	0.09	1.01
Learning abilities	T	0.27	1.47	0.14	1.06	0.10	0.50
	B	0.90	0.50	0.12	0.92	0.29	1.49
Locus of control	Internal	0.21	0.99	0.17	1.18	0.10	0.83
	External	0.23	1.02	0.13	0.85	0.15	1.18
Attention focus	T	0.18	1.43	0.11	1.04	0.05	0.45
	M	0.13	1.10	0.10	1.01	0.09	0.85
	B	0.06	0.46	0.10	0.92	0.19	1.65
Cognitive strategy	Inductive	0.16	1.07	0.14	0.91	0.14	1.03
	Deductive	0.18	0.95	0.21	1.07	0.17	0.98
Verbal IQ	T	0.23	1.16	0.14	0.95	0.09	0.78
	B	0.20	0.86	0.18	1.04	0.16	1.19
Nonverbal IQ	T	0.19	1.08	0.22	0.91	0.14	1.02
	B	0.13	0.88	0.22	1.09	0.11	0.96

[a] For factors "gender", "locus of control" and "cognitive strategy" linguistic variables "T" and "B" have been replaced by more relevant ones.

Table A2 Conditional probabilities $P(x, y)$ and Yule's coefficients of colligation $C_{F(x,y)}$ calculated for the interface parameter "type of dialogue"

Human factor	Linguistic variable	Adjustments of the interface parameter FP2 "type of dialogue"					
		FP2-1		FP2-2		FP2-3	
		$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$
Gender	Male	0.17	0.89	0.20	1.07	0.16	1.04
	Female	0.19	1.12	0.15	0.91	0.13	0.95
Learning abilities	T	0.11	0.61	0.21	1.14	0.19	1.24
	B	0.24	1.37	0.15	0.83	0.11	0.73
Locus of control	Internal	0.09	0.55	0.19	1.13	0.20	1.39
	External	0.25	1.44	0.16	0.90	0.10	0.65
Attention focus	T	0.04	0.45	0.14	0.96	0.15	1.57
	M	0.07	0.79	0.17	1.17	0.09	0.94
	B	0.16	1.74	0.13	0.87	0.05	0.51
Cognitive strategy	Inductive	0.13	0.88	0.18	1.33	0.14	1.11
	Deductive	0.20	1.08	0.22	1.30	0.14	0.89
Verbal IQ	T	0.17	1.25	0.17	0.98	0.13	0.81
	B	0.12	0.75	0.20	0.98	0.23	1.23
Nonverbal IQ	T	0.19	1.02	0.21	1.03	0.15	0.95
	B	0.15	0.98	0.16	0.96	0.14	1.07

Table A3 Conditional probabilities $P(x, y)$ and Yule's coefficients of colligation $C_{F(x,y)}$ calculated for the interface parameter "level of help instructions"

Human factor	Linguistic variable	Adjustments of the interface parameter SP1 "level of help instructions"					
		SP1-1		SP1-2		SP1-3	
		$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$
Gender	Male	0.17	0.94	0.17	1.03	0.19	1.02
	Female	0.17	1.06	0.14	0.96	0.16	0.97
Learning abilities	T	0.26	1.34	0.05	0.75	0.20	0.80
	B	0.12	0.64	0.08	1.26	0.29	1.21
Locus of control	Internal	0.12	0.71	0.13	0.87	0.25	1.43
	External	0.22	1.27	0.17	1.11	0.12	0.67
Attention focus	T	0.19	1.48	0.10	1.32	0.04	0.33
	M	0.11	0.88	0.08	1.09	0.13	1.10
	B	0.09	0.67	0.05	0.64	0.20	1.59
Cognitive strategy	Inductive	0.25	1.11	0.10	1.11	0.10	0.60
	Deductive	0.25	0.81	0.10	0.81	0.27	1.18
Verbal IQ	T	0.16	1.15	0.07	0.46	0.22	1.40
	B	0.15	0.88	0.27	1.44	0.13	0.67
Nonverbal IQ	T	0.15	0.85	0.28	1.34	0.12	0.73
	B	0.17	1.18	0.10	0.58	0.18	1.33

Table A4 Conditional probabilities $P(x, y)$ and Yule's coefficients of colligation $C_{F(x,y)}$ calculated for the interface parameter "form of data representation"

Human factor	Linguistic variable	Adjustments of the interface parameter LP1 "form of data representation"					
		LP1-1		LP1-2		LP1-3	
		$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$
Gender	Male	0.13	0.72	0.22	1.04	0.19	1.21
	Female	0.20	1.29	0.17	0.93	0.10	0.73
Learning abilities	T	0.18	0.99	0.20	1.04	0.14	0.93
	B	0.17	0.99	0.17	0.94	0.15	1.06
Locus of control	Internal	0.21	1.05	0.18	1.02	0.10	0.85
	External	0.20	0.94	0.18	0.96	0.14	1.12
Attention focus	T	0.16	1.24	0.11	0.88	0.06	0.78
	M	0.11	0.85	0.14	1.12	0.08	0.97
	B	0.12	0.85	0.13	0.95	0.11	1.22
Cognitive strategy	Inductive	0.16	0.91	0.17	1.07	0.12	0.99
	Deductive	0.23	1.05	0.18	0.92	0.15	0.99
Verbal IQ	T	0.24	1.41	0.15	0.93	0.07	0.52
	B	0.13	0.63	0.20	1.04	0.22	1.38
Nonverbal IQ	T	0.13	0.68	0.21	1.10	0.21	1.27
	B	0.22	1.40	0.14	0.89	0.09	0.67

Table A5 Conditional probabilities $P(x, y)$ and Yule's coefficients of colligation $C_{F(x,y)}$ calculated for the interface parameter " colour palette"

		Adjustments of the interface parameter "colour palette"			
		LP2-1		LP2-2	
Human factor	Linguistic variable	$P(x, y)$	$C_{F(x,y)}$	$P(x, y)$	$C_{F(x,y)}$
Gender	Male	0.23	0.88	0.30	1.05
	Female	0.25	1.04	0.24	0.90
Learning abilities	T	0.32	1.00	0.22	0.93
	B	0.27	0.93	0.22	1.02
Locus of control	Internal	0.32	1.31	0.16	0.68
	External	0.19	0.72	0.33	1.30
Attention focus	T	0.17	0.94	0.17	1.06
	M	0.17	1.00	0.15	1.00
	B	0.19	1.05	0.15	0.94
Cognitive strategy	Inductive	0.31	1.15	0.14	0.78
	Deductive	0.29	0.88	0.26	1.18
Verbal IQ	T	0.14	0.62	0.32	1.34
	B	0.35	1.30	0.20	0.58
Nonverbal IQ	T	0.38	1.35	0.17	0.62
	B	0.13	0.55	0.33	1.40

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