CHAPTER 6

DISCUSSION OF RESULTS, IMPLICATIONS AND LIMITATIONS

6.1 INTRODUCTION

This Chapter analyses the results of the experimental stages of the research. A number of implications for the design of AH applications are discussed, as are the identified limitations of the research.

6.2 RESEARCH SUMMARY

The term cognitive style has been used in the research to refer to the individuals' preferred and habitual approach to organising and representing information [Riding & Rayner, 1998]. Cognitive styles are considered to be the specific stable approach of each person to knowledge acquisition; given their individual and non-changing character, these have the potential to provide significant basis for designing adaptive interfaces for Web-based learning materials.

To identify key characteristics of cognitive styles that could impact the design of adaptive interfaces for Web-based learning materials, an extensive review of different models and classifications was carried out, together with a critical appraisal of various educational AH systems. Findings from past studies evaluating the influence of cognitive styles on the learners' preferences and performance were also analysed. This review highlighted the proliferation of models and labels referring to cognitive and learning styles. Also, that the emphasis of adaptive systems implementing cognitive or learning styles had mainly been on the pragmatics of modelling psychological constructs for their use in computer systems or adapting already existing models into specific architectures. It was also observed that the contention between what is technically possible and its effectiveness seemed to be aggravated by the fact that past empirical evaluations had produced contradictory results as to whether cognitive styles interact with the students' preferences and learning performance.

The case was argued for using Riding and Cheema's model of cognitive styles [Riding & Cheema, 1991] since it synthesises extensive previous research in the field. The

model comprises two dimensions of analysis: the *Wholist-Analytic* and the *Verbaliser-Imager* styles; these respectively refer to the habitual way in which an individual processes information and to their habitual mode of representing information when thinking. An additional advantage of using this model was the availability of a computer administered assessment test to determine the style of the students in both dimensions of analysis – the VICS & E-CSA-WA test [Peterson, 2003].

Defining attributes of cognitive styles were identified and organised under Riding and Cheema's dimensions of analysis, and some instructional conditions that capitalise on these characteristics were outlined. The identified characteristics of cognitive styles and their advantageous instructional conditions were then used in combination to derive a series of variables for the design of adaptive interfaces for Web-based learning materials, namely sequence of instruction, content presentation, content structuring, control strategy and differentiated feedback.

It was argued that in the past most educational AH systems had focused on specific aspects, such as content sequence, control strategy or mode of presentation. In contrast, the proposed approach would require the use of a series of adaptive variables and strategies in combination. While the implementation of a multivariable approach was devised as complex but feasible task from the technical point of view, a more important issue was the extent to which such an approach would enhance the individual learning performance and experience of learners.

In order to gather empirical evidence to support the development of a fully functional AH system and to determine the extent to which an adaptive system based on the variables identified would improve the students' learning experience and their performance, a prototype was developed.

LEARNINT was implemented using material form the "Computer Hardware" online learning module available to students of the MSc (IT) degree at Heriot-Watt University. It comprises two extreme interfaces: one is imager and wholist (W/I) and the other is verbal and analytic (A/V).

LEARNINT was used as a test vehicle to investigate the implications of using key characteristics of cognitive styles for the design of adaptive interfaces for Web-based learning materials. An initial evaluation was carried out to assess the extent to which matching the interface style to the learners' cognitive style improved learning efficiency. Based on the findings of this initial study, a need was determined to carry

out an extended evaluation aimed at validating the results obtained and exploring the possible relationship between cognitive style, Interface Affect and learning performance under different interface conditions.

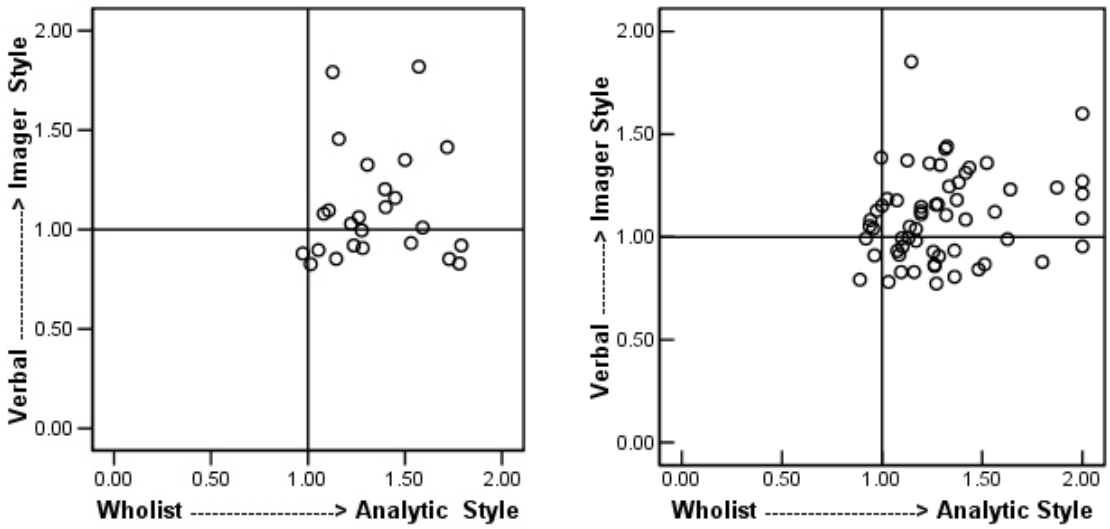
6.3 THE EVIDENCE GATHERED THROUGH THE EMPIRICAL EVALUATION OF LEARNINT

The results from these evaluation studies are discussed next, along with their limitations and the implications they have on the design of adaptive interfaces for Web-based learning materials.

Both the initial and the extended evaluations of LEARNINT suggest that for the majority of students using Web-based learning materials learning performance may improve if they experience positive affect towards the style of the interface being used.

Conversely, the initial considerations about the influence of cognitive style in learning performance under different interface conditions have not been proved. While the cognitive styles identified in the learners that participated in the evaluation studies show a distinctive distribution, the relationship between cognitive style and learning performance or between cognitive style and the participants' preferences is less clear.

Figure 6.1 compares the distribution of cognitive styles among the participants of the initial and extended evaluations of LEARNINT. As can be seen, in both cases the majority of the participants showed an *Analytic* style, and from these, more than fifty percent scored as *Imagers*. Considering that, with just one exception, all the learners that took part in the studies were postgraduate students from different fields in science and engineering, the observed distribution of cognitive styles cannot be deemed valid for other groups of students. Nevertheless, given the consistent pattern observed from the first and second samples of participants, it seems that the cognitive style test is, at the very least, informing research about the characteristics of this particular group of students in terms of their approach to gathering and processing information [Riding, 1997; Riding & Rayner, 1998].



Initial evaluation – Participants' cognitive styles, $n = 25$.

Extended evaluation – Participants' cognitive styles, $n = 60$.

Figure 6.1: Comparing the cognitive styles of the participants in the initial and extended evaluations of LEARNINT.

On the other hand, the lack of a clear influence of cognitive style over learning performance or Interface Affect makes it very difficult to elucidate the exact nature and relevance of this relationship. During the initial experiment, the correlation between the position of the participants in both dimensions of cognitive style and their expressed preferences was not significant, and the same was observed between cognitive style and learning performance. In the case of the extended evaluation, a significant correlation was observed between the *Wholist-Analytic* cognitive style dimension and the participants' preferences and learning performance in the A/V interface. However, cognitive style did not significantly contribute to the variance observed in terms of Interface Affect or learning performance. These results, supported by previous research in the field, suggest that the relevance of this relationship is still unclear.

The issue of familiarity with the style of the interface was explored further in the extended evaluation of LEARNINT, showing a significant correlation with Interface Affect, which however was not statistically significant. As it has been discussed in the thesis, when an individual faces a situation that demands learning, their cognitive style interacts with various other internal and external factors. The students' approach to learning and the kind of strategies put in place for achieving success greatly influence the interaction with the learning context. In particular, it has been suggested that this strategic approach to learning relates to their previous success in similar learning settings [Riding & Rayner, 1998; Schmeck, 1988; Diseth & Martinsen, 2003].

While the results from the extended evaluation of LEARNINT showed that familiarity with the style of the interface highly correlated with Interface Affect, this relationship did not significantly contribute to the variance observed in the participants' evaluation of the interfaces or their learning performance. Although the sub-scale built to measure the participant's familiarity with the style of the interfaces used during the experiment showed acceptable reliability (α = .822), further work is consider necessary exploring the constituent dimension of this concept. Therefore, familiarity cannot be proposed as an adaptive variable at the present.

The relationship between Interface Affect and learning performance remains therefore as one of the main findings of the experimental studies conducted for the research. Evidence gathered indicates that the style of the interface has a significant impact on the affect that learners experience while interacting with Web-based learning materials; in turn, Interface Affect influences their learning performance. This suggests that the majority of students would perform better if they experience positive affect towards the style of the interface in use.

The interface styles available in the LEARNINT prototype were designed upon a series of variables derived from an extensive analysis of the main factors on which cognitive styles have been differentiated, namely **sequence of instruction**, **content presentation**, **content structuring**, **control strategy** and **feedback**.

During the experimental evaluation of the prototype, user perceptions about the interface style were captured using a questionnaire. In particular, the questionnaire used during the extended experiment (Appendix C), from which an extensive statistical analysis was carried out (see Chapter 5), was organised into five sections, closely related to the identified adaptive variables, as shown in Table 6.1.

Evaluation Questionnaire Sub-scales	Adaptive Variables
▪ Sequence of the content	▪ Sequence of Instruction
▪ Mode of presentation	▪ Content Presentation
▪ Layout	▪ Content Structure
▪ Navigation ▪ Ease of Use	▪ Control Strategy

Table 6.1: Subscales of the evaluation questionnaire and their relationship with the proposed adaptive variables.

The statistical analysis carried out shows acceptable reliability for all the subscales in the questionnaire (see Table 5.4). In addition, the components obtained from the rotated factor analysis of the questionnaire closely reflect the structure used and the set of questions for each subscale (see Tables 5.5 and 5.6). Multiple regression of the results obtained from the questionnaire indicates that **mode of presentation**, **content** and **structure** of the learning materials account for more than 70% of the variance observed in terms of Interface Affect and more than 60% of the variance in learning performance (Tables 5.13 and 5.14). This suggests that while these variables account for the greatest variance in the results, layout and navigation are still significant for the overall results.

While the statistical analysis of the data gathered in the research suggest that these variables account for the greatest differences in Interface Affect and learning performance at the individual level, some authors also support the use of these variables. Sadler-Smith & Smith [2004], for example, suggest including *mode of presentation*, *structure of learning content* and *curriculum sequencing* as the main features for acknowledging and accommodating individual differences in styles and preferences within flexible learning environments. Also, Riding & Rayner [1998] argue that in terms of system presentation, decisions have to be made about the requirements of each individual learner in terms of *conceptual structure*, *type of content*, *information layout* and *mode of presentation*.

It has to be noted that while adaptive feedback was identified as one of the main variables to provide adaptive Web-based learning materials, it was not implemented in the LEARNINT prototype. The main reason for this was that adaptive feedback is a specialised area of research within the broader field of Computer-Assisted Assessment (**CAA**). Computers can be used to deliver, mark and analyse formative, summative or diagnostic assessment tasks that can be supervised or non-supervised [Brown & Race, 1999; Seale, 2002; Bull & McKenna, 2004]. A specific case of CAA is the delivery of Computer-Based Tests (**CBT**), where a predefined set of questions is presented to all students participating in the assessment process [Seale, 2002; Lilley et al., 2004; Lilley & Barker, 2005]. As opposed to the approach of CBT, where the assessment task is not tailored for the specific ability of individual students [Lilley et al., 2004], Computer Adaptive Tests (**CAT**) seek to offer each student a set of questions that is appropriate to their level of ability [Jettmar & Nass, 2002; Lilley et al., 2004; Lilley & Barker, 2005]. In addition to differentiated questions, adaptive feedback can also be provided to suit the individual learner. Adaptive algorithms within CAT are generally based on Item

Response Theory (**IRT**) [Boomsma et al., 2001], a family of mathematical functions used to predict the probability of a student answering a question correctly. While the implementation of these functions requires a considerable development effort, findings from different studies [e.g. Jettmar & Nass, 2002; Lilley et al., 2004; Lilley & Barker, 2005] suggest that the CAT approach does not disadvantage students and might have a reassuring effect on them, which also may improve their performance.

All things considered, the adaptive variables proposed in the research stand as good candidates for providing adaptive interfaces for Web-based learning materials. Some issues relating to the implementation of such an approach are discussed next.

6.4 IMPLICATIONS FOR THE DESIGN OF ADAPTIVE INTERFACES FOR WEB-BASED LEARNING MATERIALS

The evidence gathered through the empirical evaluation of the LEARNINT prototype contributes to the requirement analysis for the design of educational AH systems, putting particular emphasis on the need for adaptive interfaces for Web-based learning materials.

The main findings derived from the experimental stage of the research are presented below, including a brief description of their implications for the design of educational AH systems:

- For the majority of students that participated in the experimental evaluation of the LEARNINT prototype, learning performance improved in the interface style to which they expressed a more positive affect.

  Implication - Adaptive interfaces that accommodate learner needs and preferences may improve the learning performance of students using Web-based learning materials.

- The participants' cognitive style, as determined by the test used during the research, i.e. the VICS & E-CSA-WA test [Peterson, 2003], did not significantly influence Interface Affect or learning performance.

  Implications – Using the learners' cognitive style as the main determinant for the adaptive behaviour of an educational AH system may not necessarily benefit the students' experience, nor improve their learning performance. However, as it has been noted, the adaptive variables identified in the research were initially derived from the analysis of cognitive styles; therefore, using the cognitive style of each

student may provide a means for initialising these adaptive variables and the system's learner model at the beginning of the interaction. In that case, such a model should be updated dynamically based on subsequent interaction between the system and the learner [Brown et al., 2006].

- Familiarity with the style of the interface positively correlated with Interface Affect; however, this variable was not statistically significant for the observed variance.
  Implication – Further work is required exploring the constituent dimensions of familiarity and to determine a suitable way for measuring it. Current findings from the research do not support the implementation of familiarity as a relevant component for providing adaptive interfaces for Web-based learning materials.

- Learners expressed different Interface Affect under different interface conditions. Features of the interface style that had the major impact on the variance of Interface Affect and learning performance were mode of presentation, learning content and structure of the learning materials; yet layout and navigation seemed relevant too.
  Implications – These findings suggest that the adaptive variables identified in the research stand as good candidates for providing adaptive Web-based learning materials that accommodate the individual requirements and preferences of learners.

The evidence gathered, supported by previous research in the field, suggests that affective and cognitive characteristics of learners are closely interrelated: the students' affective reaction towards the learning environment will impact the kind of learning strategies they put in place to cope with the learning task, which ultimately will influence their learning performance. Accordingly, an educational AH system should possess the capability of appropriately balance the users' preferences, learning performance and affective reactions, and then decide about the most convenient configuration for the individual learner. In turn, the learner model should evolve throughout time, based on the interaction with the user, their behaviour, performance and expressed preferences, a well as affective reactions.

Further implications for the adaptive behaviour of such a system relate to the adaptive variables identified in the research:

- To provide flexible **sequence of instruction**, different types of learning content/tasks are required – e.g. theory, examples, exercises, assessment – which has a direct impact on the structure of the domain model. The sequence of presentation would depend on the current state of the learner model based on a

suitable curriculum sequencing algorithm to determine what types of learning tasks to present and in what order.

- To provide differentiated levels of **feedback**, assessment strategies are required to identify the learner's misconceptions or misunderstandings, which in turn can serve as the basis for determining what kind of exercises and revision tasks to carry out.
- In terms of **content presentation**, learning materials should be available using different media elements to convey the same content (whenever possible) according to the current state of the learner model. Accordingly, the structure of the domain should consider the provision of different media elements for the same content. Also, the curriculum sequencing algorithm has to take into account the preferred mode of presentation of the user to convey the appropriate content. A suitable mapping mechanism should exist to retrieve the corresponding media files according to the sequence of instruction determined.
- Once the sequence, type and mode of presentation are determined, the next variable is the **structure of the content**. The structure of the content refers, on the one hand, to the support provided to learners for understanding the way the learning materials are organised, such as content outlines, link annotations, concept maps, and advance and post organisers. On the other hand, decisions have to be taken about the layout of the user interface, such as whether to use frames or simultaneous windows; also about the inclusion of objects such as buttons, menus and toolbars, and whether these should be presented as graphic or verbal elements.
- Closely related to the content structure is the **control strategy** available. The system should allow for different degrees of flexibility according to the characteristics of the current learner. Some learners would benefit from structured, fixed paths through the learning material, but there would be some other students that may perform better when allowed to follow their chosen path. Navigation features such as outlines, maps and buttons should be available to the extent to which these correspond to the control strategy in place. Nevertheless, learners should always have the means to determine the degree of control that the system takes over its adaptive behaviour. Students should therefore have the possibility to activate or deactivate the adaptive functionality of the system and to modify (customise) the presentation of the learning content.

6.5 LIMITATIONS OF THE EMPIRICAL EVALUATION OF LEARNINT

A number of limitations have been identified relating to the evaluation studies carried out, which mainly involve issues of completeness and level of confidence in the results, including the following:

- The design approach was not completely evaluated because not all the adaptive variables proposed were tested. The provision of adaptive assessment and feedback was not implemented in the LEARNINT prototype.
- Reservations about the confidence level in the evaluation results may rise due to the fact that LEARNINT was not tested in an actual learning scenario; learning performance was measured in terms of information recall and under experimental conditions. It can be argued however that the evaluation studies were designed with the rigour expected in such experimental procedures, making their replication possible and contributing to the quality of the research.
- The number of participants in the evaluation studies can be considered as limited. However, the sample distributions were approximately normal, indicating that the groups of students were representative of the target population and were also sufficiently large to make inferences about the system, providing in this way general support for the design approach proposed.
- The distribution of the participants' cognitive style, as determined by the VICS & E-CSA-WA test, indicated that most students were of *Analytic* and *Imager* styles. Thus, it can be argued that the experiments did not have the same number of students from all different cognitive styles. However, sampling of participants was not carried out because the aim of the evaluation was not a comparative analysis between styles but rather to analyse the relationship between cognitive style, learning performance and user reactions at the individual level. Accordingly, testing of cognitive styles was left at the end of the experimental procedure to avoid influencing the participants' reactions.
- The use of the VICS & E-CSA-WA test for assessing the participants' cognitive style might also be seen as a limitation since it has been criticised as measuring reaction times rather than styles. Yet, the validity and reliability of the test have been well documented.

- Students that participated in the evaluations may have been unintentionally pre-selected on the basis of their academic ability: they were enrolled in Higher Education pursing a postgraduate degree. This being the case, it is not unreasonable to assume that these students have already developed a repertoire of learning strategies allowing them to deal with a variety of learning situations and tasks.

6.6 SUMMARY

In this Chapter the results from the experimental stage of the research have been discussed and a number of implications for the design of educational AH system have been identified. The evidence gathered through the empirical evaluation of LEARNINT suggest that for the majority of students using Web-based learning materials performance may improve if they experience positive affect towards the style of the interface being used. While the initial considerations about the influence of cognitive style in learning performance under different interface conditions have not been proved, a consistent pattern has been observed in the distribution of styles among the students that participated in the research. The lack of a clear influence of cognitive style over learning performance or Interface Affect however makes it very difficult to elucidate the relevance of this pattern.

Familiarity was another variable explored further during the extended evaluation of LEARNINT. It was observed that familiarity with the style of the interface highly correlated with Interface affect, but this relationship was not statistically significant in terms of the variance observed in the participants' evaluation of the interfaces or their learning performance. Further work is required exploring the constituent dimensions of this concept.

The relationship between Interface Affect and learning performance remains therefore as one of the main findings of the empirical work carried out in the research. In the same way, the lack of a clear influence of cognitive style over learning performance or Interface Affect supports previous research in the field and has to be highlighted as another important contribution of this research.

Further implications of the findings from the research suggest that the design approach underpinning the interface styles used accounted for differences in users' reactions and performance. Therefore, the adaptive variables suggested in the thesis stand as good

candidates for providing adaptivity and eventually personal interfaces for Web-based learning materials.

A number of limitations have also been identified. These relate to the completeness and level of confidence in the results of the empirical stages of the research and deserve carefully consideration for any further work to be carried out based on this piece of research.