From Novice to Expert Learner Models: Authoring adaptive user-interface behaviour to convey training needs

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1 Abstract

No past research has addressed the connection between learner models and interaction models. Nor has any previous work accounted for the dynamic modelling of interface contents based on the underlying pedagogic directives. This paper describes how cognitive and computational concepts can be applied to building multimodal interface and learner models and for maintaining model consistency throughout long-term tutorial interactions. We show an important influence of an experiment and our cognitive approach to the design of intelligent tutoring systems. This approach includes not only the notion of multiple dimensions of domain expertise but also the appropriate dialogue factors that can promote the significant aspects of fluency in human-centred, multi-modal dialogues. A substantial part of the theoretical findings has been implemented in the RUI prototype system.

1.1 Keywords

Learner modelling, multimodal interface design, intelligent tutoring systems, authoring systems, tutoring shells

2 Authoring adaptive interfaces

Recent accounts of Intelligent Tutoring Systems (ITS) architectures attribute a key role to interface design [1], claiming that knowledge should be communicated in different modalities (e.g., by applying a variety of tutorial styles and their corresponding presentation formats). This can be achieved by applying cognitive principles to the design and behaviour of interface objects. Yet, there has been little effort in detailing the nature and content of these objects. It is indeed observed that the usability of graphical user interfaces relies to a large extent on the spatial arrangement of their visual elements [2,3,4], but the efficacy of any interface depends critically on the meaningful connection between the interface objects and their pedagogic function.

To capture the semantics of the real world more precisely, AI and HCI researchers have proposed several symbolic formalisms for knowledge representation. One such method, WYSIWYM [5], explicitly tries to deal with complex conceptual input by means of a multi-language, feedback text generator to provide an authoring framework for defining knowledge bases. The method and the tools are organised around the idea of "what you see is what you meant" as the author is presented with natural language text to convey the intended meaning of standardised graphic input.

Except for some syntactic differences of knowledge descriptions, previous formalisms and tools offer similar notions for representing world concepts, their features and their classification. Because of that, just using an existing knowledge representation formalism is not sufficient to facilitate a human author when creating the interface of a complex, multi-model knowledge-based system, like an ITS. Indeed, the interface authoring process is a cyclic, time-consuming task. It is often influenced by uncertainty in the way authors decide between one knowledge structure or another to represent an interaction model; i.e., several different representations may reflect the same model. Additionally, interface modelling is also characterised by an intuitive and empirical methodology. As a result, the quality of the representations obtained tends to be dependent upon the author's experience and insight in the domain of expertise as well as in interface design.

However, even when authors manage to produce reasonable interface resources by using any modelling formalism and authoring tool, it does not follow that they will be able to keep such representations appropriate throughout long-term interactions [6]. This can be a problem in ITSs, for example, since training systems are often meant to be used for long-term expertise development purposes rather than just for brief interactive help-like tasks. As the learner becomes more skilled in the subject domain, the system interface is expected to change dynamically, according to his or her evolving capacities, to convey new training needs. This raises the need for highly interactive, multimodal, adaptive systems that, so far, are not found even in the intersection between the research areas of ITS and HCI.

3 Background on learner and interface modelling

It has long been pointed out that one of the main bottlenecks for building adaptive systems is largely due to the lack of knowledge about the user's beliefs [7]. In particular, dynamic learner modelling has populated many research areas of ITS since updating long-term records accordingly is a major issue. The loss of synchronism between the human mental models and those of the system triggered a full array of more general related problems, such as the over-general learner model [8]. Some have even proposed ways of managing tutorial dialogues while bypassing the "intractable problem of student modelling" [9].

Dynamic learner modelling differs from the more traditional view of user models of help systems in that the latter tends to consist of a short-term record [10]. Besides, user identity and evaluation is much more severe in learner modelling then in any other short-term user profiling mechanism.

On the one hand, Bull and Pain [7] argue that the main reason for the large and established learner modelling architectures and tools lies in that such systems include well founded cognitive principles for the definition and implementation of such an intricate internal machinery of an ITS. On the other hand, Murray [11] observes that authoring tools still lack appropriate resources for building and integrating the learner model with the interface model. In other words, despite the apparent success of authoring systems, no-one has so far addressed the connection between learner models and interaction models. Nor has any previous work accounted for the dynamic modelling of interface contents based on the underlying pedagogic directives that are appropriate for the long-term development of certain human skills and capacities.

If ITSs are to accommodate the development of the domain expertise of their users, the learner interface must be informed by models of expertise — i.e., interface parameters and the way in which they progress over time.

4 An Experiment

As a testbed for our investigation, we choose the domains of complex visual categorisation and diagnosis, particularly those of medical Radiology. Medical diagnosis is a hard task, especially when combined with the perceptual abilities required for the recognition of detailed visual patterns. Despite this, expert radiologists — unlike novice trainees — can accurately identify major abnormalities in just a few seconds [12].
We report here on an experiment to assess the multiple, evolving capacities of an expert radiologist.

4.1 Aims

The aims of the experiment are three-fold:

- To confirm previously identified capacities of expertise reported in the literature [12];
- To determine any additional capacities not yet described or formalised in previous research;
- To determine the multimodal inputs trainees use to provide evidence of their capacities under constrained teaching procedures.

Briefly, this was done in order to identify which means and formats, in addition to natural language, were utilised as inputs and outputs during the discussions and how they compared to each other in relation to the evolving diagnostic identified.

4.2 Methodology

We conducted and recorded a series of training sessions between an expert radiologist and junior doctors. The design of the experiment was informed by extensive consultations with expert radiologists to determine the scope of abnormalities to train on, the most appropriate teaching approach to use and the subjects to be involved.

In order to highlight primarily the novice-to-expert differences, we chose a case problem that demanded as much experiential knowledge as possible to reach a diagnosis, while keeping principled knowledge dependencies to a minimum. The case problem involved two easily confusable classes of abnormality — Ewing sarcoma and osteosarcoma. Only one medical problem, focussing on a confirmed diagnosed case of Ewing sarcoma, was applied throughout the experiment to all trainees.

The ultimate goal was for each trainee to reach a correct diagnosis. This was a task that first and second-year trainee radiologists often failed to accomplish.

The expert radiologist conducted tutorial dialogues with the trainees on a one-to-one basis, using a bottom-up teaching approach by allowing the trainees to begin with their own hypothesis (starting with scattered image features). As a supplementary tutoring directive, the expert was also asked to interfere fairly often to make trainees externalise their reasoning chain. This was expected to give trainees a better chance to exhibit consistency and completeness aspects of the diagnosis.

The experiment involved as subjects, 16 junior doctors of varying levels as trainee radiologists: six in their first-year, five second-years, four third-years and one final-year student.

4.3 Results

After observing and tape-recording the sixteen training sessions, text-based transcriptions were made for each session. The transcriptions capture verbal as well as other

[1] In real tutorial dialogues, experts normally approach the trainee in a top-down fashion [13]. Despite this, we chose the former teaching approach since our focus here is not on optimising teaching styles, and since a bottom-up approach is more likely to reveal the reasoning behind the trainees' judgements.

means of interaction. Figures 1 and 2 show excerpts of dialogue transcriptions.

T: *Please, provide a description of tissue -bone conditions in the classical sequence.*
J1: Let me see if the anatomy is preserved, according to what I know. If there is ... <Request for help> ...
T: *What can you say about the bone texture?*
J1: By comparison, I cannot see any alteration of bone texture between the left and the right members ...

Figure 1: Excerpt of a dialogue with a novice trainee.

In Figure 1, "T" is the expert radiologist tutor and "J1" is a junior doctor in the first -year as a trainee radiologist. As a novice, J1 is capable of stating only principled knowledge, such as anatomy, physiology and the projective geometry of radiography. Because of that, he needs help most of the time.

In Figure 2, "J2" is a junior doctor in the second -year as a trainee radiologist. As an intermediate -level learner, J2 is not expected to reach the major abnormality (Ewing sarcoma) but is already able to detect the main visual features in the image and determine that it is a case of tumoral process and not an inflammatory one.

T: *Please, provide a description of tissue -bone conditions in the classical sequence.*
J2: Firstly, from the outside to the inside parts, soft tissue, and then, the bone features: axis, shape, texture, structural organisation, ... relationship between the cortical and the medular ... margin of the articular space ...
T: *What can you say about the bone texture?*
J2: Drawing both the tibial and femural lines of the affected member, and comparing it with the normal one, I can see a slight variation of the inferior part ... and a slight misalignment of the of the proximal portion o f the metafisis ... there is also lowering of bone density ... and the presence structural disorder with bone material production ...

Figure 2: Excerpt of a dialogue with an intermediate trainee

4.3.1 Features of Expertise

We carried out a comprehensive analysis of the 16 dialogues to identify the features (capacities) of expertise. Fifteen capacities (shown below) were observed from the dialogues.[2] The first five of these have also been identified in previous research [12]. For reasons of brevity, we will briefly focus on the 6th and 15th identified capacities.

1. 2D-3D mapping;
2. Speed of Diagnosis
3. Providing differential diagnosis;
4. Selecting discrimination features;
5. Easy recall of peculiar;
6. Searching for hardly visible features;
7. Perspective view of disease evolution;
8. Expressing conclusive justifications;
9. Explicit reporting of logical relations between features;
10. Accurately detecting disproportional features;
11. Consistency of symbolic relations;
12. Completeness of feature detection and reporting;
13. Technical vocabulary;
14. Inferring totally invisible features;
15. Structuring their reasoning (and reporting).

Capacity 6: As part of their experiential knowledge, experts are good at spontaneously looking for visible features that are not obviously present because they actually expect to see such features as a consequence of the major abnormality. This happens even when the features are faded to the most extreme situations since the full skills of an advanced-level radiologist allow him or her to work out the diagnosis through top -down analysis (from the major abnormality to the image findings). In Figures 1 and 2, the second question made by the tutor had very different answers from J1 and J2, showing that J2 already possesses some expertise for this capacity.

Capacity 15: Experts are good at structuring their reasoning because they have developed meta -level procedural knowledge to unify the way they systematically approach any analysis of any abnormality through visual features. In Figures 1 and 2, Trainee J1 immediately requests help because he strongly lacks this capacity.

4.3.2 Multimodal behaviour

We observed that the trainees engaged in a variety of multimodal behaviours during the sessions:

- Inspecting visual images;
- Pointing at visual features to focus attention;
- Inspecting text -based descriptions of clinical and bio-physical data;
- Writing text-based diagnosis;
- Measuring 2D portions;
- Manipulating contrast and brightness;
- Browsing through slices;

5 Implementation in an ITS

A substantial part of the theoretical findings has been implemented in an existing ITS, called RUI [6]. It consists of *(1)* an authoring language and tools for managing the complexity of ITS design, and *(2)* a domain -independent model of dialogue interpretation, integrated with the tools, for controlling adaptive tutorial interactions.

At the instructional level, RUI introduces a new model of interpretation for guiding dialogues about visual images which combines meta -level knowledge with domain -specific teaching knowledge. Figure 3 shows a snapshot of the Learning Tool interface. The Learning Tool allows the

[2] A detailed explanation of each one can be found in [14].

student to explore example images using a database browser interface or, alternatively, to interact in a Socratic way with a guided tutorial interface. In more general terms, it makes use of Lesgold's duality approach on expertise acquisition in radiology (principled vs experiential knowledge), proposing that principled knowledge can be acquired by free exploration of the image database browser and that experiential knowledge can be acquired through guided dialogues.

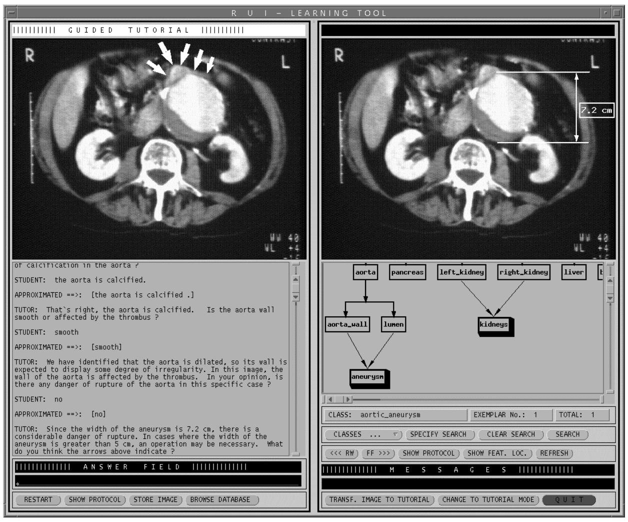

Figure 3: Snapshot of the Learning tool's interface.

RUI's Learning Tool comments on learners' partial diagnoses of images, critiques inconsistencies in such diagnoses, indicates important areas of the image with graphic elements, and gives continuity to the dialogue by asking about other abnormal image features. It guides the interaction by monitoring learners' actions as they progress with their hypotheses and by offering intelligent feedback whenever they deviate from accurate diagnoses. To achieve these goals, we have extended the Learning Tool with a domain-independent model of dialogue interpretation based on four mechanisms: *(1)* feature visibility; *(2)* anatomy granularity; *(3)* the propagation of domain-specific teaching/protection rules and *(4)* default teaching actions.

The feature visibility mechanism makes use of visibility information, available from annotated image descriptions, matching it against the learner's diagnosis and, if necessary, providing feedback. Basically, it directs the student in understanding and recognising anatomical features not directly visible in an image but still inferable through a relationship with other features features.

Sometimes a learner's diagnosis, although not incorrect, may require more detailed information to be considered accurate. The anatomy granularity mechanism aims at tuning the student's perception on where exactly, in the anatomical structure, the abnormal feature is situated.

The third mechanism refers to the propagation of domain-specific teaching rules. RUI's dialogue interpreter traverses the knowledge structures defined for the a class of abnormality being considered, searching for related domain-specific rules and giving them control precedence over the other three domain-independent mechanisms (1, 2 and 4 above). Depending on the conditional clause of a rule, the dialogue interpreter may fire the body of actions of this rule, propagating the effect on the learner model, which may result in the selection of another rule by this mechanism thus repeating the cycle. Through this mechanism, the Learning Tool avoids the problem of over-general student beliefs [8] by eventually firing actions of domain-specific rules which are specially designed by the domain expert to enhance the power of explicit advice.

Finally, the *default teaching actions* mechanism can also be activated by the model of dialogue interpretation to discuss the value (V) of a feature (F) in an anatomical component (C). However, default teaching actions are generated automatically by meta-level procedures that simply combine V, F and C to construct discourse structures in a slot-filling way. It is only executed whenever the dialogue interpreter does not find a domain-specific rule referring to F and C in focus. In other words, even if the expert does not define any domain-specific rules in the authoring level, the dialogue interpreter, combining this mechanism with the first two mechanisms (feature visibility and anatomy granularity), is still capable of guiding tutorial interactions with learners.

Figures 4 and 5 show constrained dialogues conducted through the RUI system with learners of different levels of expertise, under the general model of interpretation described above.

6 Interface-Oriented authoring tools

Before RUI [6], no domain-independent method for ITS design has focused specifically on the representation of visual concepts. Computer tutors for visual concepts differ from other tutoring systems in that the skills to be communicated to students are closely linked to the interpretation of image patterns as a primary task. Such systems must therefore include facilities for students to manipulate and display large stocks of visual images. Likewise, design methods and tools for producing these tutors must provide experts with mechanisms for creating and assigning high-level, symbolic descriptions to such images.

Ongoing work in RUI is exploring and implementing a number of classes of interface objects, called ITWs (Intelligent Tutoring Widgets), so that domain experts can easily create system-active and system-passive tutorial interactions by directly manipulating such objects. This is achieved with a visual programming authoring tool which offers access to the more internal knowledge structures of an ITS (domain knowledge, student model and pedagogical directives) through the definition of the interface module in an object-oriented, event-driven style.

Tutor: *Click the mouse on all calcified areas of the lesion.*
Learner: <mouse-clicks>
Tutor: *Is the margin of the lesion mainly sharp or graded?*
Learner: graded.
Tutor: *The lesion is mainly sharp. Make an interactive measurement of the lesion size.*
Learner: <use of measuring resources>
Tutor: *Choose one of the following options:…*
Learner: <mouse-click>
Tutor: *What do you think the arrows above indicate?*
Learner: The aorta is affected by the thrombus.
Tutor: *The aorta as a whole is not affected by the thrombus. Can you be more specific by pointing which subpart(s) of the aorta is?*
Learner: <mouse-click> …

Figure 4: Human-computer dialogue with a novice user

Tutor: *Give a diagnosis for this case.*
Learner: The cortical grey is affected by the lesion.
Tutor: *This is not a feature of pituitary adenoma. It can be associated with meningioma, for example. The image opposite shows a case of meningioma where the cortical grey is affected by the lesion. What is the size of the lesion?*
Learner: It is markedly enlarged.
Tutor: *You have overestimated the size of the lesion. It appears to be only slightly enlarged. Do you find any abnormal features referring to the aorta wall?*
Learner: The aorta wall appears to be smooth.
Tutor: *This is not consistent with our previous findings. We have already identified that the aorta is dilated, so its wall is expected to display some degree of irregularity. Draw a line that delimits the aneurysm.*
Learner: <use of drawing resources>

Figure 5: Human-computer dialogue with an intermediate user

7 Conclusion

Finally, in the context of ITS evolution, although impressive results have been accomplished around prototype tools, most ITS authoring tools and tutoring architectures still remain as proposals. Aimed at different tutoring philosophies, these domain-independent systems place emphases on different aspects of the instructional process but invariably overlook interface-oriented authoring issues.

We are in the early stages of developing a facility for allowing an ITS created with RUI to have its interface easily changed (not only during the authoring phase but also dynamically, during a tutorial session). This will be based on information derived from knowledge of the learner model as well as the pedagogic model. However, new computational concepts are needed for authoring dynamic and versatile interface elements for ITS which can cope with the complex phenomenon of knowledge communication (from expert to machine and from machine to student) and with the role of different media when designing learning environments.

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