A Usability Evaluation of Graphical Modelling Languages for Authoring Adaptive 3D Virtual Learning Environments

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Abstract: Adaptive three-dimensional (3D) Virtual Learning Environments (VLEs) offer many advantages for learning, but developing them is still far from easy and is usually only done by specialized people. However, involving teachers in the development of learning material is essential. One way to support teachers in authoring adaptive 3D VLEs is the use of domain specific modelling languages as such languages provide a high level of abstraction. In addition, graphical languages are recommended for non-technical users. Although such an approach, i.e. graphical domain specific modelling languages, seems to be promising there is a need for evaluating this in practice. Usability and acceptance could become a problem because the authoring process could become relatively complex. This paper reports on a pilot evaluation performed to evaluate the use of graphical modelling languages for designing (i.e. authoring) adaptive 3D VLEs.

1 INTRODUCTION

To come to effective and challenging adaptive Virtual Learning Environments (VLEs), it is essential to involve educators and experts in the subject domain, in the development of the VLE. However, developing a 3D VLE is still quite a technical issue, and adding adaptivity to such an environment does not make it easier. Supporting or involving educators in the development of adaptive 3D VLEs is still in its infancy. Therefore, this is a priority for our research.

In the context of educational games, it is already noted that involving educators in the development of educational 3D games can be achieved by providing user friendly, effective and efficient authoring tools (Overmars, 2004; Marchiori et al., 2011). This is also what we want to achieve for 3D VLEs. Therefore, we proposed a set of easy to use graphical Domain Specific Modelling Languages (DSMLs) for authoring adaptive 3D VLEs (Ewais and De Troyer, 2013).

The rationale behind using graphical languages is that graphical specifications are, in general, easier for the communication with non-technical people. They make it easy to convey information, as many people can think and remember things in term of pictures (Boshernitsan and Downes, 2004). Furthermore, they can provide appropriate abstractions that make the specifications easier (Moody, 2009). However, they should be defined with care to be usable and effective.

In general, DSMLs are languages that use a specific vocabulary dedicated to the modelling and designing a specific class of problems (Deursen et al., 2000). They are particular well suited for domain experts as they use the vocabulary of the domain rather than some general modelling language vocabulary. Mostly, DSMLs are graphical languages.

Giving due consideration to the usability of software is essential. Good usability provides different advantages: improved user satisfaction, increased usefulness and effectiveness, improved ease of learning and use, reduced training and support costs. Therefore, we conducted a pilot evaluation of the graphical DSMLs proposed for authoring adaptive 3D VLEs. The primary aim of the conducted evaluation was to reveal if we had chosen the right direction with these DSMLs and if they were usable for the task of specifying an adaptive storyline-based 3D VLEs.

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Section 2 briefly describes the graphical languages. Section 4, 5 and 6 present respectively the evaluation and its results. Section 7 concludes the paper.

2 AUTHORING ADAPTIVE 3D VLE

Based on our previous work done in the context of the EU-project GRAPPLE (De Bra et al., 2010) and insight obtained from a literature review, we proposed a new approach for authoring adaptive 3D VLEs (Ewais and De Troyer, 2013). The kernel of the approach is a set of three DSMLs: one for expressing the pedagogical structure of the underlying learning domain (the Pedagogical Model Language), one to define the (adaptive) learning path (i.e. storyline) for the course (the Adaptive Storyline Language), and one for specifying the 3D adaptivity inside the different topics of the course (the Adaptive Topic Language). We described each language briefly.

The Pedagogical Model Language (PML)

To define the pedagogical structure of the adaptive 3D VLE, the authors can connect learning concepts (defined in the Domain Model[1]) via Pedagogical Relationships Types (PRTs) (see Figure 1).

A typical example of a PRT is the *prerequisite*. The goal of this PRT is to define when a learning concept is a prerequisite for another learning concept meaning that the learner needs to study the first concept before he can start learning second concept. Other possible PRTs are *Defines*, *Illustrates*, *Interest*, *Propagates_knowledge*, and *Update_knowledge*.

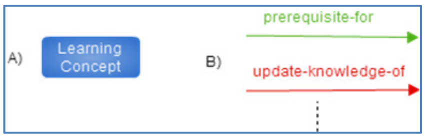

Figure 1: PML elements: A) learning concept B) Pedagogical Relationship Types (PRT).

The PRTs are associated with *Pedagogical Update Rules* (*PURs*), which are condition-action rules. This rule mechanism is used to define how the knowledge of the learner (kept in the User Model[2]) should be updated, i.e. a rule defines how and which User Model attributes should be updated. When the learner follows the course, the PUR of a PRT is triggered on accessing the source learning concepts of the PRT.

The general format for the PURs is as follows:

```
IF <user_model_condition>
THEN <user_model_update_actions>
```

Different PRTs are predefined. In general, the predefined PRTs and their associated update rules (PURs) are sufficient to accommodate common pedagogical relationships between learning concepts in different domains. However, authors can define new PRTs or change default PURs.

An example Pedagogical Model is given in Figure 2. The learning concept *Sun* is a prerequisite for the learning concepts *Mercury*, *Venus*, *Mars*, and *Earth*. The PUR associated with this *prerequisite-for* PRT is given in the callout symbol. Furthermore, when the learner learns about *Mercury*, his knowledge about *Venus* will also increase. This is specified in the PUR associated with the *update-knowledge-of* PRT between *Mercury* and *Venus*. This PRT is also applied to other concepts: *Venus*, *Mars*, and *Earth*.

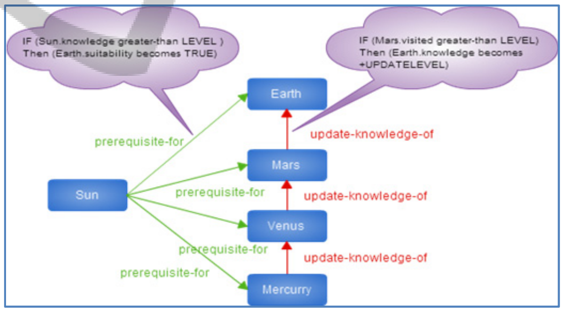

Figure 2: Pedagogical Model for a number of learning concepts related to a Solar System Course.

Adaptive StoryLine Language (ASLL)

This language allows defining a learning path inside a 3D VLE (i.e. storyline) by enables the authors to define a set of topics and connecting them. Next, the author can also indicate how this storyline should adapt to the individual learner.

Decomposing the storyline into different topics is used to reduce complexity. Topics can be compared to chapters in regular courses. To express the adaptivity of the storyline, each topic is connected with a next topic via a so-called Storyline Adaptation Rule. An example is given in Figure 4. Figure 3 shows the graphical notations of ASLL. Note that a storyline has a start and end. Start and end symbols (Figure 3 (A) and (F)) can be used to

[1] The Domain Model defines the learning concepts. It is outside the scope of this paper.
[2] The User Model is a typical model used in adaptive systems. It captures all information about the user, like preferences and his knowledge about the learning concepts.

specify the textual and/or audio/video messages to be presented to the learner at this point. Such messages can e.g., be used to instruct the learner what to do or what he achieved. Furthermore, for a Storyline Adaptation Rule (Figure 3 (C)) the arrow points from the source topic to the target topic. Rules should be given a meaningful name in order to increase the readability of the model.

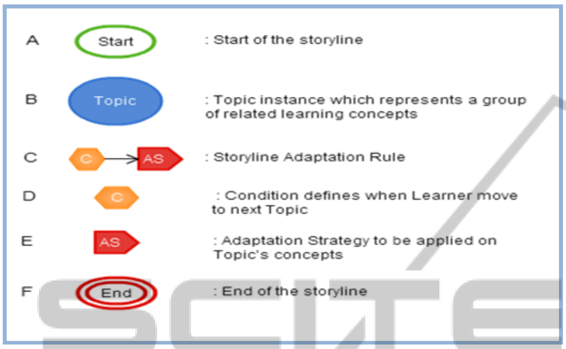

Figure 3: ASLL elements: A) Start of a storyline; B) Topic in a storyline; C) Topic Adaptation Rule; D) condition; E) Adaptation state; F) End of a storyline.

A Storyline Adaptation Rule is a condition-action rule. The condition (Figure 3 (D)) specifies when the learner can proceed from the source topic to the target topic, and is, in general, based on the learner's knowledge level about the source topic and the suitability of the target topic. The action part (Figure 3 (E)) is used to specify what kind of adaptation should be applied to the learning concepts involved in the target topic. Example adaptations are marking learning concepts with bounding boxes or annotations, hiding learning concepts, or providing a guided tour to the concepts related to the topic. Possible adaptation are predefined, see (De Troyer et al., 2010).

Figure 4 shows an example of an adaptive storyline for a course about the solar system. The storyline is composed of the topics: *Learning About Stars, Inner Solar System, Moons, Outer Solar System,* and *Advanced Topics*. The learner will start with a guided tour for the topic *Learning About Stars*. After acquiring the required knowledge for this topic, the learner will be directed to a new topic, either to the *Outer Solar System* or to the *Inner Solar System*, depending on the truth-values of the conditions associated with the two storyline adaptation rules. For instance, the storyline adaptation rule between *Learn About Stars* and *Inner Solar System*, is as follows:

IF 'Learn About Stars'.knowledge greater than 90
AND 'Inner Solar System'.suitability is TRUE
THEN APPLY 'markobject' **TO** 'Inner Solar System'

The rule states that if the learner's knowledge about topic *Learn About Stars* is above the specified value and the suitability of topic *Inner Solar System* is true, then the *markObjects* adaptation should be applied to the learning concepts of the *Inner Solar System* topic.

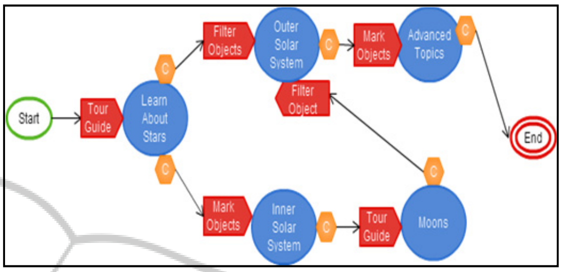

Figure 4: Adaptive Storyline for 3D VLE Solar System Course.

Adaptive Topic Language (ATL)

This language allows describing how the content related to each topic should be adapted to the individual learner, i.e. it allows specifying the adaptivity within a single topic. This is done by means of adaptation rules between learning concepts. The rules are event-condition-action rules. They are triggered by activities performed in the 3D VLE. Figure 5 shows the symbols used in ATL.

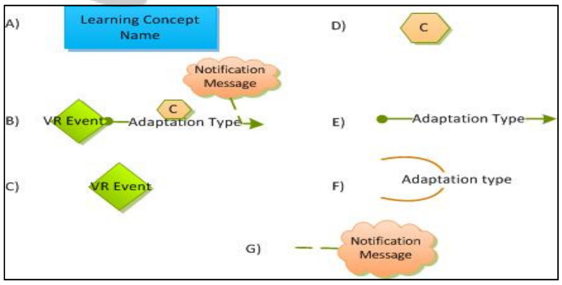

Figure 5: ATL elements: A) Learning concept, B) Adaptation rule, C) VR event, D) Condition, E) and F) Adaptation type to be applied to a 3D learning Concept, G) Notification Message.

A topic is composed of a set of learning concepts (Figure 5 (A)). Learning concepts are connected through so-called Topic Adaptation Rules. A topic Adaptation Rule (Figure 5 (B)) has a source (learning concept) and a target (learning concept). The event part of the rule (Figure 5 (C)) specifies the event that will trigger the rule. This event has to occur with the source. The rule will only be executed when the condition in the condition part (Figure 5 (D)) is true. The action part (Figure 5 (E) or (F)) specifies the adaptation to be applied on the target learning concept. Version (E) is used when source and target are different; version (F) when source and target are equal. Also a notification or feedback message to the learner can be specified (Figure 5 (G)). This message will be shown when an adaptation rule is applied. A set of predefined adaptation types is available (De Troyer et al., 2009). Figure 6 shows an example Topic Adaptation Rule. This rule will be fired once the learner "comes close to" (VR event) *Sun*. Next, the condition of the rule will be evaluated. Here, a test on how often the learner already interacted with *Sun*. If this is higher that the specified value, the action part is executed, i.e. *SemiDisplay* adaptation type will be applied to *Earth* to display *Earth* is a semi way.

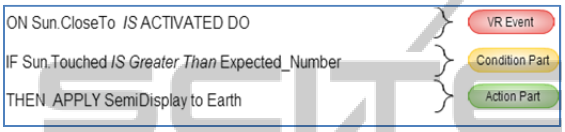

Figure 6: Example topic adaptation rule.

VR events are used to indicate when the adaptation rules should be evaluated. The VR events are events related to the learner's activities inside the 3D VLE, e.g., interaction with a 3D object or navigating to a 3D object. The condition must be satisfied in order to actually perform the action-part of the rule. The condition will in general deal with the learner's preferences, his learning background, and progress, but may also consider previous activities performed by the learner in the 3D VLE (captured by so-called 3D VLE activity history attributes). By including conditions on previous activities performed by the learner in the 3D VLE, the author is able to control the learner's behaviour in the 3D VLE, e.g., to avoid that the learner wastes too much time by playing around.

Two examples adaptation rules are given in Figure 7. The first adaptation rule (Figure 7(A)) is between two different learning concepts (*Sun* and *Earth*). The VR event *close to* will trigger the rule. When the rule is applied, the adaptation type *display* will be applied to the target (*Earth*) to display the

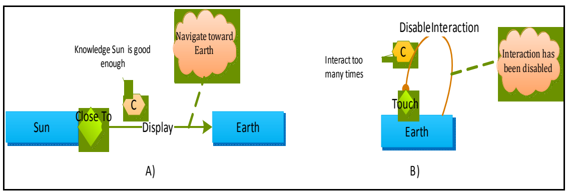

Figure 7: Examples of adaptation rules: A) adaptation rule between two learning concepts; Sun and Earth, B) adaptation rule on a single learning concept.

VR object that represents earth. The second adaptation rule (Figure 7 (B)) is on a single learning concept (*Earth*). The rule uses a *touch* VR event and the *disable_interaction* adaptation type to disable user interaction with the *Earth* 3D object once the learner has already interacted with it too many times. In both examples, a notification message is provided.

3 PILOT EVALUATION

The goal of the conducted evaluation was to perform a first evaluation of the modelling languages from a usability and acceptability point of view, in order to evaluate whether the approach taken was appropriate and to gather feedback to improve the languages before starting to implement tool support.

As we were looking for critical feedback from the viewpoint of usability and user satisfaction, we asked PhD students from our universities to participate in the evaluation. Four PhD candidates and researchers and ten instructors were involved in the evaluation. All of them were from the Computer Science department, but they were rather novice in 3D or VR.

The evaluation was divided in three steps. The first step introduced the participants to the different notations of the languages; example models created using the languages; a list of available Pedagogical Relationship Types and their default associated update rules; and a selection of possible adaptation types.

In the second step, the participants had to do an authoring task, i.e. designing an adaptive 3D VLE about the Solar System using the three languages. This authoring task was done using regular paper and pen. Because it was not our purpose to evaluate an authoring tool, but rather the level of expressiveness of the visual notations of the proposed languages and the effort needed to create an adaptive 3D VLE using the graphical languages, the use of pen and paper is acceptable. This approach also avoided that we already spent a lot of resources on the development of a software tool before receiving any feedback on the proposed languages. However, we also admit that using paper-pencil rather than an authoring tool also has some limitations. For instance, a software tool could guide the correct use of the languages; this cannot be achieved with pen and paper. To solve such issues, an instructor was responsible for guiding and helping the participants with syntactical issues.

In the third step, the participants filled in an online questionnaire. The questionnaire was carefully constructed to reduce possible bias. For instance, there were positively as well as negatively formulated questions, and questions were formulated carefully to avoid that participants might be encouraged to give more favourable answers (Lazar, Feng, and Hochheiser, 2010, p.196). Furthermore, the questions' order was in such a way that the answer to one question did not influence the response to another question. Furthermore, each participant did the evaluation individually, the results were treated anonymously, and the participants were informed that there were no right or wrong answers and that it is was not an evaluation of the participants themselves.

The questionnaire was composed of questions from six categories: Demographic Information, Authoring Adaptive 3D VLE (A3DVLE), ISONORM 9241/110-S Evaluation Questionnaire (ISONORM) (Prumper, 1999), Subjective Impression Questionnaire (SIQ) (Davis et al., 1989), Qualitative Feedback (QF), and Workload Perception (WP) (Hart and Staveland, 1988).

All questions were mandatory. As already indicated, there were positively formulated questions and negative formulated questions and all closed question had a Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). For each individual evaluation feedback on a positive question, a score of 3 or higher was considered as "good", as well as a score of 3 or lower on a negative formulated question.

4 EVALUATION RESULTS

All participants were from the domain of Computer Science, but the demographic data indicated that only few participants were familiar with VR/3D (5 out of 14 participants). However, all participants were using the computer on a daily basis. The average age was 32 (youngest was 26, eldest 36). The majority of the participants were males (11 out of 14). Only 2 (out of 14)participants reported to be inexperienced with authoring standard courses. But most of the participants (11 out of 14) had only limited experience in authoring 3D VEs or videogames in the context of e-learning. All participants were familiar with graphical modelling languages like UML.

In average, participants spent about 40 minutes on the tasks (best time was 25 min.; worst was 90 min.).

Usability:
The usability of the graphical languages was evaluated as 'Medium/Neutral' to 'Good to Perfect'. The bars chart in Figure 8 presents the results concerning both ISONORM and A3DVLE questionnaires. 8 positive formulated questions related to the A3DVLE questionnaire that were evaluated as 'Good to Perfect', while 3 questions (positive formulated) were evaluated as 'Neutral'. Concerning the negatively formulated questions in the A3DVLE questionnaire, 4 questions were rated as 'Good to Perfect', 2 questions as 'Neutral', and 1 as 'Poor'. 5 questions related to ISONORM 9241/110-S questionnaire were rated as 'Good to Perfect' and 3 questions as 'Neutral'. We now provide more details.

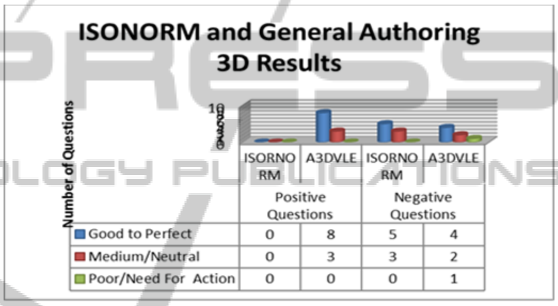

Figure 8: ISONORM and General Authoring 3D VLE Questionnaires Results.

In general, all questions related to the *suitability for the task, conformity with user expectations, self-descriptiveness, usefulness* and *easy-to-use*, were rated good. The visual notations of the modelling language allowed the participants to do the authoring task without being 3D/VR experts. The overall positive feedback on the usability questions indicates that the modelling languages are appropriate for the task. In addition, most of the participants considered the modelling languages rather intuitive. However, we have to note that the participants had a good knowledge of modelling.

However, also a number of questions received a neutral score. In particular, the questions related to the *suitability for learning* were rated as 'Medium/Neutral'. Furthermore, questions related to understanding the goal of pedagogical model were towards 'Medium/Neutral'. Although many participants agreed that there were no unnecessary input or effort, some of them spent quite some time in understanding the adaptation types provided and defining the course structure before they could start with the actual design of the adaptive 3D VLE. The question "*The defined Pedagogical Relationship Types are difficult to understand*" was rated 'Poor'.

Acceptability:
The different acceptability aspects scored in average good (see Figure 9). 4 questions related to perceived ease of use were rated as 'Good', while the other questions (3 questions) were rated as "Neutral'. Concerning the two questions related to attitude, 1 question was rated as 'Good' and the other was rated as 'Neutral'. Finally, the perceived usefulness questions (2 questions) were rated as 'Good'.

Given the fact that 11 participants (out of 14) had only limited experience in authoring 3D VLE's or videogames, we rather expected a neutral rate to the *perceived ease of use* and *attitude.* But the scores were in average good. However, some participants gave a neutral rate to the aspect *perceived usefulness*.

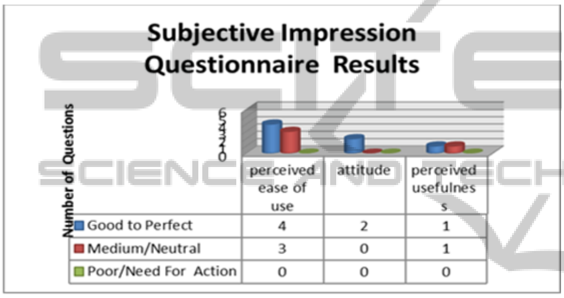

Figure 9: Subjective Impression Questionnaire Feedback.

Qualitative Feedback:
The open questions were about three aspects: *appreciation, depreciation,* and *recommendations*.

Appreciation
Most of the participants (11 out of 14) noted that they liked the fact that there are three modelling languages for creating the whole adaptive 3D VLE. Further on, ease of use and consistency was mentioned (7 times). Others (5) considered the availability of the predefined adaptation strategies, which could be applied to all 3D objects related to a topic, as very useful.

Concerning the question "*Was the Adaptive Storyline Language expressive enough to specify the overall storyline of the adaptive 3D course? (Please describe why*"), answers revealed that connecting topics with adaptation rules helped to define the overall flow of the storyline. In particular, 8 participants liked the adaptation rules between topics and the fact that they could choose which adaptation strategies to apply to the 3D objects inside the topic.

Concerning the question "*Was the Adaptive Topic Language expressive enough to specify the details of each topic? (Please describe why)*", 4 participants highly appreciated that they could specify which adaptation types to applied to different 3D objects. Furthermore, being able to define when the adaptation type should be triggered by means of a VR event helped them to obtain a general overview of when the adaptations would take place. In addition, 7 participants gave a credit to the possibility of being able to give messages to the learner.

Depreciation
In responding to the question "*What did you like least about the authoring approach in general and its languages?*" answers revealed some limitations and flaws summarized into the following categories:

- A need for software tool (3 times)
- Using different adaptation types to the same object was confusing (4 times).
- The need to specify learning concepts for each topic was confusing (1 time).
- Distinction between the adaptive storyline and adaptive topic (6 times).

The answers on the question "*Was the Pedagogical Model language expressive enough to specify the pedagogical aspects for the adaptive 3D courses? (Please describe why)*" provided some explanation why the question "*The defined Pedagogical Relationship Types are difficult to understand*" received the score 'Poor'. For instance, 6 participants needed quite some time to understand the meaning and the use of the Pedagogical Relationship Types (PRTs). Others (7) found the use of different colours for different PRTs confusing.

Recommendations
In responding to the question "*What should be improved and how?*" most of the answers were related to the need for a supporting tool. Indeed, the use of the modelling languages within an authoring tool could support the authors with different help mechanisms like tool tips and tutorials. Furthermore, it would be easier to detect errors in the models. Another issue related to a supporting tool is the fact that a tool could ease the specification/modification, e.g., by providing menu's.

Workload Perception:
Participants were requested to give feedback on the mental demand, the effort required to accomplish the task, and their frustration. Most of the answers were neutral, but some frustrations were reported. For instance, some participants were wondering whether it is the author's role to make sure that the order of learning concepts in the Storyline Model

should be consistent with the Pedagogical Model. This is indeed a fair question. However, providing an authoring tool that checks the consistency of both models can easily solve this. This is feasible as authoring tools in the context of adaptive hypermedia such as AHA! (De Bra, Smits and Stash, 2006) and GRAPPLE (Hendrix et al., 2008) already check adaptation rules.

5 DISCUSSION

Overall, the evaluation results of the graphical languages were quite positive. However, it is necessary to recall that all participants were computer scientists; this could have influenced the results. However, most of them did not have true experience with developing 3D/VR application, which corresponds with one of the main characteristics of our target users. Furthermore, conducting an empirical evaluation with a relative small number of users (14 participants in our case) may also affect the validity of the result of the evaluation. However, this evaluation was a pilot evaluation and performed in order to obtain a first feedback.

Usability and *acceptance* results were good despite the fact that most of the participants lacked experience in authoring adaptive 3D VLEs and there was no true learning period, while it is obvious that some time is required to get acquainted with the visual notations.

The *effectiveness* of our authoring approach turned out to be good in this evaluation since all participants were able to define the adaptive 3D VLE in the right way. They could specify an adaptive storyline and managed to specify adaptation for the topics. Furthermore, the decomposed specification of a topic adaptation rule, into a VR event to trigger the rule, a condition that needs to be satisfied, and the resulting action (the adaptation type), made it easy for the participants to keep an overview on the adaptations.

In addition, the qualitative feedback provided useful information for further work. As expected, tool support is essential. But also some specific requirements related to tool support were given, such as pull down menu's to select the User Model and 3D VLE activity history attributes when (re)defining the update rules in the pedagogical model, as well as when defining the adaptation rules in the adaptive topic model. Interesting to note it that in the evaluation, the 3D VLE activity history attributes and the User Model attributes were given as one list, although conceptually there are separated in our approach. We thought one list would be simpler for the author, as both categories of attributes may be needed in the context of defining the adaptive topic model. However feedback indicated that it would be better to keep this conceptual difference and to present them as two separate lists. Furthermore, the use of different colours for different Pedagogical Relationship Types surprisingly turned out to be confusing and it was advised to remove this or leave it up to the author to define when different colours should be used.

6 CONCLUSIONS

We presented and discussed a usability evaluation of graphical modelling languages developed to support 3D-novice educators in the process of specifying (i.e. authoring) adaptive 3D VLEs.

The evaluation was done with 14 people from the domain of Computer Science. After an introduction to the approach, they performed an authoring task. Next, they filled in a questionnaire consisting of closed, as well as open questions. The results indicate that the modelling languages proposed are intuitive and can be used by people without deep knowledge of 3D/VR to perform the authoring process within a fair period of time. Moreover, the participants found the visual notations easy to use. Not surprisingly, the evaluation revealed the need for software support.

We acknowledge that the evaluation has some limitations, the most important ones being: the fact that the participants were computer scientists and the limited amount of participants. Also the fact that the authoring exercise was done with pen and paper can be a limitation. On the other hand, it avoided that the tool was evaluated rather than the languages. In order to fully evaluate our approach, additional evaluations should be conducted when a (functional prototype of an) authoring tool has been developed with a larger number of people including people with different backgrounds, like experts in VR for validating the advanced features as well as non-technical people, people with and without modelling experience, and people with different teaching experience. It may also be important to measure the required time for completing the tasks by the different categories of users. If the time required to author a course is too long, people may not be prepared to use it in practise.

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