Designing Adaptable Educational Software: a Case-Study for Spatial Geometry

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Abstract: A Computer-Based Learning Environment (CBLE) needs to be adapted to several teaching styles, since this is a condition for acceptance and effective use in school. In this paper we propose to provide teachers with an opportunity for describing the learning sequences they plan to perform within the environment. Then, from these descriptions, a specific instance of the environment could be built and made available to the learners and teachers. To allow such learning sequences descriptions we need a common agreement on data, concepts and basic reasoning criteria that could be used. We describe such a process and the results we have obtained in the framework of a spatial geometry learning environment.

1. Introduction

Despite an increasing availability of technology, there are still many signs of dissatisfaction with existing educational software. It remains difficult to build complete and adequate requirements for a piece of educational software because many teachers are not yet aware of what is easily feasible and what is still difficult with the available technology. However, the participation of teachers in the design of these tools seems to be a key factor of acceptance and of effective use in schools. We have learned from many years of working with teachers involved in introducing technologies in their schools that they will not use a piece of software in which they cannot include their own know-how and that they cannot reshape according to their local needs.

Starting from those observations, we came to the conclusion that many pieces of educational software should include adaptation functionalities. Moreover, the adaptation process should remain as simple and as close to teachers' ways of working as possible. To fulfil such requirements we propose a framework for learning sequences descriptions ; from such descriptions we aim at deducing the accurate configuration of the educational software according to the learning sequence needs. To allow such descriptions we propose a model for knowledge classification and a set of "teaching" primitives".

The aim of this paper is twofold. First we describe an example of building such a set of definitions in a project for teaching spatial geometry. At the same time we focus on the methodology used in the project that could appear as another *suitably balanced marriage between the "technology push" and the "learning pull"* as suggested in [Conlon et al. 1996].

2. A Four-Level Knowledge Model

The collaborative work we have done with geometry teachers in order to design a learning environment underlined the difficulty for obtaining a consensus about the definition of the domain concepts and the functions that operate on them. These difficulties come mainly from the multiplicity of the teachers' points of view about the objectives of such an environment. We consider that these problems, that stretch from theory to implementation, can be easily overcome by using the 4-level knowledge model proposed in [Bernat et al. 1995].

By manipulating objets at the interface level of a CBLE, the user indirectly acts on an external representation of the objets of the learning domain, whereas the system reacts on an internal representation, which is not necessarily isomorphic. Then it is necessary to clearly separate domain specification mechanisms from interface specification mechanisms.

The *domain* level is a theoretical level that represents the domain knowledge to teach, independently from any symbolic-level representation. The *representation* level defines a unified *realisation* of domain concepts. This realisation is based on design choices concerning concept representation and underlines the relations between them. The represented knowledge is *reified* at the *presentation* level, which provides external points of view on domain concepts, as they are perceived by students and proposed by teachers. Finally, the *visual* level is the graphical interface level defined by the designer. It depends on the development environment for the implementation of direct manipulation.

2.1 The Domain : Teaching of Spatial Geometry

The taught geometry is a transposition of the geometrical theory, varying with respect to the progression needed for knowledge acquisition. A given concept may have different interpretations and its taught could be led according to different pedagogical activities. For example, the *cube* concept varies according to its use : it may be a *composite object* (i.e. composed of 8 points, 12 edges and 6 faces) or a *solid object* (i.e. taken as a whole object).

2.2 The Unified Representation

The *representation* level implements a unified representation of the different concepts to teach, i.e. the geometrical objects, the relations between them and the functions that apply to them. It underlines a unique conceptual facet that defines and represents the properties of an object. For example, the cube can be defined from 4 points and particular properties : the two first points define the initial edge of the cube; the third point belongs to a circle perpendicular to this edge and defines the first face of the cube; the last point is one of the two intersections between the circle and a perpendicular line to the first face, thus giving the cube volume.

2.3 The Presentation Points of View

The *presentation* level is an interface level that contains multiple views of the same concepts. This level allows the teachers to express most of their didactical choices : from the choice of one concept presentation depends the learning situation induced by the utilisation of the environment. In the context of a spatial geometry environment, the different presentation choices can be divided into three groups : the *visual units for comprehension*, the *geometrical objects* and the *interaction modes*.

2.3.1 The Visual Units for Comprehension

In spatial geometry, the interpretation of the plane projection of a spatial construction is a major difficulty. In order to make a scene easier to read, we introduce some *visual units for comprehension*. They are independent from domain concepts and thus could exist in fields other than geometry. For example, reference axes could be useful for understanding the position of an object in space [Fig. 1] but their precise kind may vary : traditional axes, grids, walls (i.e. a space delimitation by three perpendicular planes), …

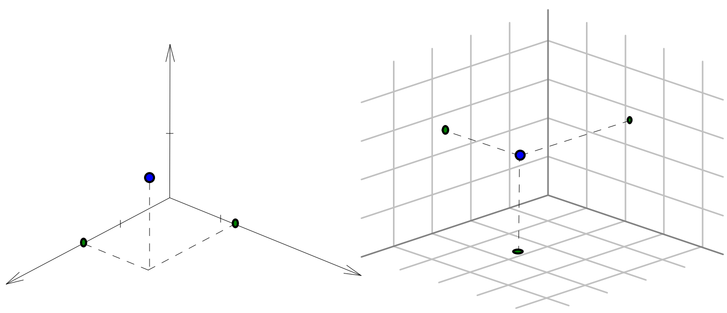


Figure 1: Perspective of the space and object position with reference axes (left) and with three perpendicular planes or 'walls' (right)

The choice of a particular *visual unit for comprehension* depends on the learning context and on the user's knowledge. For example, reference axes are useless in solid geometry learning (i.e. constructions based on a solid like a cube or a sphere) : the existence of strong cultural connotation objects could indeed be enough to provide good space reading. Some visual units like the *walls*, useful at the beginning of the spatial geometry learning for scaffolding, should be progressively removed.

2.3.2 The Presentation of Geometrical Objects

The choice of the presentation of geometrical objects also depends on the didactical situation that the teacher wants to realise. The cube, for example, may be presented as a *'wireframe'* cube (all the edges are visible) or a *'hidden faces removal'* cube (the edges behind the cube are hidden). The *'hidden faces removal'* cube is suitable for solid geometry (presented as a physical object, with a volume) although the *'wireframe'* cube would more underline its induced properties (e.g. opposite edges parallelism). The same problem happens for the choice of planes presentation [Fig. 2]. Shall we reify a plane by presenting it as a rectangle included in this plane (but which plane; what about the risk of misconception induced by limiting its visual dimension) ? Wouldn't it be better to adapt each presentation of the plane to the global presentation context (for example, presented by its intersection with the walls, if any) ? There is no unique solution to this question : the final presentation choice depends on the teacher, who is able to appreciate the relevance of a given solution.

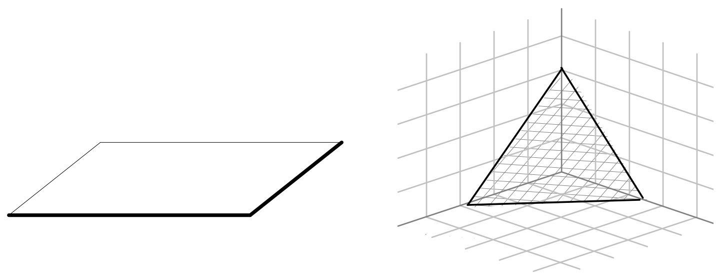


Figure 2: Presentation of a plane as a parallelogram (left) and by its intersection with the 'walls' (right)

2.3.3 The Interaction Modes

An interaction is a user's action, immediately followed by visual feedback and by a system's reaction. For example, direct manipulation of a point is one of the essential actions in a dynamic geometry environment. Moving a point according to the three dimensions of space cannot be performed by a simple mouse move. In order to restitute the third dimension, it is necessary to define a more complex task (e.g. combining mouse move with pressing a given key). Feedback has to clearly underline what kind of action is involved. Then the point could move according to user's expectations : a mouse move should involve a similar cursor move and the point move should follow the cursor's movement on the screen. In the CABRI 3D environment [Qasem 1997], the solution consists in decomposing the move of a point in a horizontal plane then along a vertical line (modification of the point elevation). Another method, based on the walls as a visual unit for comprehension, consists in directly dragging the projection of a point in the different walls. Whatever the chosen method is, it is necessary to decompose any movement in space in a set of movements in the plane, in order to avoid ergonomic ambiguities. Moreover, such a decomposition could offer a pedagogical interest.

2.4 The Objects Visualisation.

At the *Visual* level, the different objects presentation attributes are translated at the interface, according to the properties defined in these presentations : the points shape (round, square, …) and size, the lines thickness, the object colour, … This level also allows to define the communication vocabulary : geometrical notations, support messages, menus and items names, dialog boxes, …

3. Learning Sequences Description

Specifying a CBLE necessarily requires a collaboration between people from different backgrounds (didacticians, psychologists, designers and, above all, teachers) [Guin 1994] and thus needs a common language, understandable by everyone. Consequently, this specification has to be based on the *Knowledge-level* perspective [Newell 1982], [Nicaud 1994], a level of knowledge description that is independent of any symbol-level representation. For the teachers, it has to ease the expression of their know-how and pedagogical purposes, i.e. their choices concerning the *knowledge presentation* and the *activities* they want to manage around this knowledge. In particular, this specification mechanism has to allow the *author-teachers* (the teachers who directly collaborate in the design process) to define the teaching *domain* and to propose both geometrical objects *presentations* and their *visual* properties, and the *user-teachers* (the teachers who need CBLE adaptation) to select, among the available choices, those which will create the didactical situation.

Our method was to provide author-teachers with a frame, called *utilisation context*, for learning sequences description based on the activities they want to set using the CBLE. In a mid-term perspective, we hope to be able to specify information stemming from these descriptions using *ontologies*.

3.1 Utilisation Context

The presentations of a given object and the actions that could be applied to it are dependent on the context in which this object is used. Here we are closely akin to one of the principles of the KACTUS project [Laresgoiti et al. 1996] : "*the context can be seen as a "viewpoint" taken on the object. It is usually impossible to enumerate in advance all the possible useful viewpoints on (a class of) objects*".

We define a *utilisation context* as the information frame needed for performing activities that share the same pedagogical objectives. From these objectives and reference activities, it is possible to define the representative object classes of this context, their presentations and the user-available functions. In order to illustrate the *utilisation context*, let us consider the following example [Fig. 3].

Context : "*Cube section - Exercises*"

Objective : intersection of a cube by a plane.

Reference activities : exercises 1, 2, 3

Including contexts :
Cube section - Tutorial
Polyhedrons section - Exercises […]

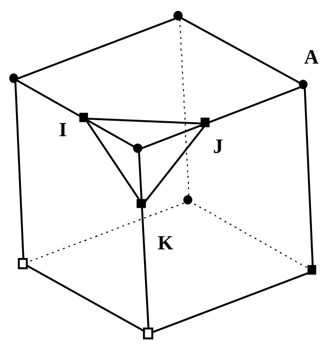
Characteristics :

Object class:	**Facets :**	
Cube	wireframe , hidden line	
Plane	*all*	[…]

Functions :
Construction of a parallel line
Construction of a midpoint
Construction of an intersection […]

Environment parameters :
Perspective : cavalier […]

Difficulties and supports :
{ specify the available supports, that are used by teachers }



Exercise 1 : constructs the intersection of the cube and a plane, parallel to the section (IJK) and going throw the point A.

Figure 3: Definition of the utilisation context "Cube section - Exercise".

The author-teachers wanted to manage a particular *activity* and thus decided to describe a *context* named *"Cube section - Exercises"*. They specified the *objective* of this context and defined its *characteristics* that in their view will allow the student to satisfy this objective.

In this context, some particular presentations of *plane* and *cube object classes* stand out : the cube could be presented either as *'wireframe'*, or as a *'hidden line'*. On the contrary, the *'hidden face removal'* presentation is not suitable in this context : it does not allow the user to visualise the required intersections. These various required presentations of an object class are defined as *facets*. The *functions*, that allow the student to perform construction tasks, are specified : the parallel line, midpoint and intersection between two lines construction tasks. From their experiences in providing such activities in the classroom, teachers have identified several types of *difficulties* and have built several *supports* to allow the learners to overcome them. In particular, they proposed some software-based supports, like the *visual units for comprehension* [see § 2.3.1] or the perspective type, that are specified in the *Environment parameters* field.

3.2 Toward Teaching Ontologies

According to [Gruber 1995], an ontology is an *explicit specification of a conceptualisation*, i.e. an explicit specification of a simplified representation of a world for a given purpose. An ontology is composed of different entities of the domain (e.g. object classes, relations, functions, … depending on the domain to abstract), the definition of which associates a human-readable description with formal axioms that constrain their interpretation. The main purpose of an ontology is to allow people to *commit* to it, i.e. to come to an agreement to use the given shared vocabulary in a coherent and consistent manner. Ontologies are mainly used for expert knowledge sharing and reuse but, more recently, for also managing pedagogical knowledge [Murray 1996].

3.2.1 Construction of the Ontology

Only the *author-teachers* are able to improve the ontology. The ontology is incrementally built from each *utilisation context* by specifying every new entity, or by enriching existing ones, that appear in the context : functions, objects, facets, … Each new entity is then added to the ontology. In the previous *utilisation context* for example, author-teachers used a c*ube* and the *midpoint construction* function, that had to be defined respectively as *object class* and *function* entities and included in the ontology [Fig. 4].

Object Class "*Cube*"

Description :
A cube is a polyhedron made up of 8 vertices, 12 edges and 6 faces. Edges are [...]

Composed of :
{A,B,C,D,A',B',C',D'} set of Points
[...]

Constraints :
(perpendicular, (AB),(AC)) *{relation}*
[..]

Facets :
wireframe [...]
hidden line [...] *{points of view}*
Hidden faces removal [...]

Function "*Midpoint construction*"

Description :
Construct the equidistant point from 2 points.
[...]

Facets :
Midpoint of a segment :
function : Segment $\rightarrow$ Point
[..]

Midpoint of two points :
function : (Point, Point) $\rightarrow$ Point
[..]

Figure 4: Extracting the ontology entities

They described the *cube* object class by giving a short description and a formal definition (composition, geometrical constraints, …). In particular, they specified the different cube *facets*. The definition of the *midpoint construction* function required arity and arguments kind specification . It also refers to the *'Point'* and *'Segment'* entities that also need to be specified as object classes of the ontology.

3.2.2 Use Of Ontologies For Educational Software Adaptation

Until now, adaptation of an educational software to each user's specific expectation is only provided at the interface level. The CABRI environment [Laborde et al. 1994], for example, allows a user to configure all available functions by directly manipulating menu items. In CALQUES 2 [Bernat 1994], it is possible to select different interaction modes in a dialog box.

Such a parametrisation cannot be extended to too complex systems : the concepts points of view (and, consequently the parameters) are often too numerous and cross-dependent. Our *utilisation contexts* allow us to overcome this complexity. Indeed, they define a set of coherent parameters with respect to the context objective. Choosing a context can be done by a unique operation that automatically implies a parameters set.

Moreover, the context descriptions can be organised in a context library and made available to other teachers. Thus, the *user-teachers* could consult the library and choose a well-adapted context to the activity he would like to propose, avoiding to always begin from scratch.

4. Conclusion

In this paper, we have presented an attempt to provide teachers with a framework for describing their teaching needs with respect to educational software adaptation. The proposal includes a four level model for knowledge categorisation as well as utilisation contexts. The four level model has been successfully used to describe several teaching requirements at the appropriate level. The utilisation contexts have been used on the one hand to describe learning sequences and on the other hand to build step by step a type of teaching ontology for spatial geometry. Such an ontology will then be available for further context designs. Moreover, we expect that it will be part of larger pedagogical libraries available to teachers through networks in the schools of tomorrow.

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