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Pedagogical plans as communication oriented objects

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ABSTRACT

This paper focuses on pedagogical plans intended as objects to support human communication. Its purpose is to describe a structural model for pedagogical plans which can assist both authors and users. The model helps authors to engage in the design of a plan as a communication project and helps users in the process of understanding, customizing, enacting and evaluating an existing plan.

A distinctive feature of the model is the adoption of a hierarchical representation where each plan can be represented as a hierarchical network of constituent elementary plans that focus in on more specific parts of the learning process, thus going from more general to more concrete, detailed levels. This makes it possible to approach plan authoring as a top-down process, something that presents considerable advantages. It is a valuable aid for mastering the complexity of design and at the same time represents a maieutic factor that encourages authors to establish levels of conceptualization and abstraction which would otherwise remain unexpressed. The user too comprehends the plan in terms of a top-down process, where the specific steps of a learning activity are seen as originating from more general and abstract conceptualizations. In this way communication and understanding are enhanced and facilitated. The paper provides an easy-to-understand example of a hierarchical plan and describes a prototype tool that has been developed for managing hierarchical plans. Finally some preliminary results are presented from initial application of the model and the associated tool in the context of an international research project on educational innovation in mathematics.

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1. Introduction

The work reported here originates in the framework of ReMath[1], an international research project on technology-based educational innovation in the area of mathematics. The main role of pedagogical planning within ReMath was to support the process of communication and cooperation among the different actors involved in the project, principally educational researchers and teachers. In this process, the pedagogical reasoning underpinning specific choices in plan design was of paramount importance. For educational researchers in ReMath, pedagogical plans were to provide a concrete basis for comparison and cross-experimentation of different theoretical approaches and different educational tools. Conversely, for teachers plans played the role of vectors of educational innovation to be suitably customized for the specific situation where the plan was to be enacted.

Another dimension of pedagogical planning was that of fostering a maieutic process through which authors could gain greater awareness of the pedagogical rationale underlying their design choices (Britain, 2007). To this purpose, the underlying representational model assumed a pivotal role as a conceptual tool capable of bringing to the fore all the relevant pedagogical elements at play, some of which might otherwise remain obscure.

Pedagogical planning in ReMath focused on communication and pedagogical reasoning, so the specific educational area – mathematics – did not impose strong requirements on how pedagogical planning was to be modelled. Consequently the model which was developed has a wide scope and, in principle, is applicable to any educational content area.

To identify a suitable structural model for pedagogical plans, the area of learning design was surveyed and the main existing approaches were considered. Although learning design is intended in a variety of manners in the literature, one general unifying characteristic is the

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presence of an artefact as a focal point of the design process. This artefact can be defined as “a description of the playing out of a learning situation or a unit of learning aimed at the acquisition of a precise body of knowledge through the specification of roles and activities, as well as knowledge handling resources, tools, services and results associated with the implementation of the activities” (Pernin & Lejeune, 2006). Definitions of this kind are sufficiently broad to accommodate a wide range of interpretations and approaches. Indeed researchers in the field adopt a variety of terms to denote such artefacts (learning design, learning scenario, pedagogical scenario, didactical scenario, etc.), which differ greatly as to the nature of the meaning invested in them. In ReMath, the term pedagogical plan was adopted, a term which conveys an overriding concern to foster consideration for, reflection on, and understanding of critical pedagogical and contextual aspects entailed in the design and enactment of learning activities.

In recent years, alongside the variety of approaches, we have also witnessed the emergence of a certain number of modelling languages aimed at representing these educational artefacts in a formal, machine-readable manner. Presently, IMS-LD is the most widely adopted of these languages. It “aims to represent the learning design of units of learning in a semantic, formal and machine-interpretable way”. However, “the knowledge of the learning designer himself is not captured by the IMS-LD Learning Design, which only represents the result” (Koper, 2006). Consequently, approaches based on the adoption of specific design languages such as IMS-LD or Learning Design Language (LDL) (Martel, Vignollet, Ferraris, & Durand, 2006) were considered to be unsuitable for ReMath's purposes.

The focus on production and management of machine-interpretable design artefacts is also a characteristic of the LAMS system (Dalziel, 2003). LAMS is an integrated system that seeks to support rapid, “teacher-friendly” generation, customisation and running of learning sequences (Philip & Dalziel, 2004). While this has undoubted advantages in time-and-effort saving, and thus in fostering practitioner take-up, it is not primarily intended to support critical pedagogical and contextual reflection[2]. LAMS sequences, and those generated with IMS-LD based tools, can generally be classified as “runnable” design artefacts ii as opposed to “inspirational” ones, to use the distinction adopted by (Falconer, Beetham, Oliver, Lockyer, & Littlejohn, 2007). Inspirational designs tend to be more educator- than learner-oriented, and as such are closer to the pedagogical plan concept. Many undertakings based on such artefacts seek to foster reuse through degrees of abstraction. This is the case with learning patterns, which identify types of (collaborative) learning structures appropriate for meeting particular goals; these can be used as basic building blocks for constructing an instantiated learning design (Hernández-Leo et al., 2006; Strijbos, Martens, & Jochems, 2004). Other authors explore the potential for sharing and reuse through abstraction (Conole and Fill, 2005) and in a similar vein by separation of disciplinary, contextual and pedagogical concerns (McAndrew & Weller, 2005).

The approach described herein adopts Falconer's (idem) view of the design process, a process that “calls upon contextual, tacit and experiential knowledge … its place within, and links to other aspects of the process needs to be evident.” As illustrated hereafter, the pedagogical plan artefact seeks to embody this crucial knowledge, articulating it in a hierarchical structure that incorporates degrees of abstraction suitable for supporting reflection, communication and reuse.

2. Modelling communication-oriented pedagogical plans: basic requirements

As already mentioned, the representation model for pedagogical plans is oriented to human communication rather than to computer-based enactment. This entails three major requirements that, although not completely independent of each other, can reasonably be dealt with separately. These are: (1) expressive power, i.e. the capability to accommodate the relevant information; (2) facilitating power, i.e. the capability to facilitate communication, especially important in the case of complex plans; and (3) flexibility, namely the possibility to cope easily and naturally with different communication needs.

2.1. Expressive power

The concept of expressive power has been formally defined by computer scientists in connection with formal languages (Dantsin, Eiter, Gottlob, & Voronkov, 2001). The term refers to two basic questions: what can be said in a given language and how it can be said, the former question being very formal in nature and the latter more qualitative and communication oriented. The concept of expressive power fits well in the area of pedagogical plan modelling. Here the expressive power of a model can first be defined as its capability to host all the categories of information which are relevant for a given group of users. This means that expressive power is not an exclusive property of a model but is more generally an attribute of the relation between a model and a target group of users. A second aspect of expressive power is its capability to convey concisely and naturally the relevant information in such a way that the information can be easily found and that relationships can be readily understood. This is illustrated in the case of ReMath, where pedagogical plans were intended as a support for pedagogical investigations. It was very important here that all the relevant levels of information, from general conceptions to concrete details, could find their place in the model in such a way that the links among them could be as self-evident as possible.

2.2. Facilitating power

To make a potentially complex message more readily understandable, several conditions must typically be satisfied. Two of these appear particularly relevant for pedagogical plans: minimal completeness and gradual access to complexity. The former refers to the information contained in a pedagogical plan, while the latter relates to the structure given to that information. Completeness is the most obvious property: if part of the message is missing, understanding is usually more difficult. Conversely, an excess of information can inhibit understanding through information overload, diminished interest or lack of detailed knowledge on the part of the receiver, etc. The term minimal completeness means “just enough”, i.e. a message that provides what is required for understanding without including anything

[2] Over recent years efforts have also been directed towards endowing the LAMS system with a layer specifically for promoting pedagogical reflection in the design process and for supporting the adoption of “pedagogically sound” methodologies. These efforts have partly derived from the JISC Pedagogic Planner project (http://www.jisc.ac.uk/whatwedo/programmes/elearningpedagogy/phoebeplanner.aspx) and have resulted in the implementation of the LAMS “Activity Planner” function (http://wiki.lamsfoundation.org/display/planner/Activity+Planner) along with other ongoing development initiatives.

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more. Minimal completeness does not exclude redundancy, which in many cases can be exploited as a facilitating factor. As pedagogical plans can be considered structured messages of a particular type, the concept of minimal completeness may be directly applied. It is worth mentioning that minimal completeness is a relative property, i.e. the same pedagogical plan can be more or less minimally complete depending on the target it addresses. The need for minimal completeness has a direct bearing on the pedagogical plan model, which needs to be an adaptive structure capable of including all the descriptive elements required in a given situation and of excluding (or hiding) the unnecessary ones. This has an obvious link with the third requirement, flexibility.

The conceptual tools most typically adopted to tame *complexity* are decomposition and abstraction. When combined, these give origin to a further tool, namely hierarchical organization. The idea of using hierarchical organization for mastering complexity and enhancing communication has been firmly consolidated in computer science theory for some time (Dahl, Dijkstra, & Hoare, 1972). It is also well established in the area of educational design, where it was first introduced by (Gagné, 1965). In addition, hierarchical organization has been widely used in the area of task analysis (Gagné, Briggs, & Wager, 1992; Jonassen, Tessmer, & Wallace, 1999), leading to the development of specific support tools (Lee, 2004). To a certain degree, hierarchical organization has also been adopted, more or less explicitly, in the area of learning design. For instance, in IMS Learning Design, environments (<imsld:environment>) can be nested so as to originate the hierarchical organization of learning objects and services (Klebl, 2006). Recently, some authors have mentioned desirable properties which may facilitate both developers and users when dealing with complex plans: a) the possibility to navigate a plan by zooming in or out as circumstances demand (Falconer et al., 2007); and (b) the possibility to easily see plan specifics in a wider context and as part of an overall vision (Britain, 2007). Both properties are intrinsic to hierarchical organization, which in this sense seems to provide a natural answer to plan complexity. In the case of pedagogical plans, hierarchical organization means that it should be possible for a plan to be decomposed-into or expressed-in-terms-of more elementary plans. This opens the way to representation models which can make a plan both easier to read and understand, and more flexible as well (as discussed later).

2.3. Flexibility

Representation models providing a high degree of flexibility are a key factor in making pedagogical plans suitable vehicles of communication between different actors at different moments and in different circumstances. For example, in some situations it may be appropriate to convey the overall gist of a plan and thus focus at a general, abstract level. On other occasions, attention may need to be directed towards very concrete aspects, thus calling for consideration of details. Hierarchical organization lends itself very naturally to the building of plans which convey the most appropriate level of generality/detail. Since hierarchical organization naturally supports a process of top-down refinement, it becomes possible for a plan designer to push refinement until the required degree of detail has been achieved. In principle, it is also possible to extract different plans at different levels of a hierarchical structure in order to satisfy different communication needs. Stopping the refinement process before the maximum level of detail is reached (e.g. when seeking to convey only a general idea about a given plan) is not necessarily tantamount to a lack of completeness, something which would necessarily undermine the facilitating power requirement. Indeed, the principle of abstraction implies that each level of refinement should be complete (i.e. self-consistent and therefore fully understandable) without any references to other more detailed levels (otherwise the minimality condition would be contradicted).

A pedagogical plan should typically encompass an appropriate set of descriptors and, possibly, a collection of resources to be used at enactment time either by teachers or by learners. Ideally, the descriptor set should be open-ended and fully customisable both in composition and structure of individual components. In this way, communities would be able to develop specific descriptor sets that reflect their priorities and meet their particular needs, possibly by means of ontological mapping (Jovanović, Gašević, Knight, & Richards, 2007).

Seen in terms of authors' particular requirements and characteristics, flexibility also means making provision for a variety of different design styles. Some authors organize their plans by contents; others may wish to start from a more abstract level, say by adopting a general design pattern that provides a basic structure and subsequently instantiate and populate this with specific contents or content-related activities. Still others may wish to blend the two approaches. Ideally, a representation model for pedagogical plans should have the flexibility to support a variety of design styles without binding authors to any single predetermined approach.

3. The ReMath pedagogical plan model

This section describes the model adopted for representing pedagogical plans. It begins with a description of elementary plans, i.e. the single entities (nodes) of the hierarchical structure that are not further refined into more elementary plans. Then a detailed description is provided of hierarchical organization.

3.1. Elementary plans

Drawing on the considerations of Conole and Fill (2005), elementary plans comprise three distinct conceptual areas, with the purpose of fostering reflection on the pedagogical aspects of design. The first area aims at specifying the educational *Target*, i.e. what the outcomes of learning should be, who the learners are and in what context learning takes place. The second area specifies how learning should take place by providing *Specifications* for the envisioned learning activities. More specifically, this includes description of "activities and roles as well as knowledge handling resources, tools, services and results associated with the implementation of the activities" (Pernin & Lejeune, 2006). Besides descriptions, this area can also accommodate the actual resources and tools (or links to these) to be used by teachers and learners during enactment.

The third area specifies the *Pedagogical Rationale* underpinning the different aspects of a plan (learning outcomes, educational strategies, choice of tool, etc). Specifically, pedagogical rationale includes the author's primary motivations (e.g. tackling a typical learning problem with a new approach), positioning of the plan's key ideas in terms of disciplinary/interdisciplinary concerns, significant innovation that the plan embodies, and, possibly, the theoretical framework that has informed its design.

The three areas are intended as flexible entities that can assume different structures to satisfy the requirements imposed by different contents and different communities of users. Structural differences may include the use of different descriptors and adoption of different description languages (from natural to formalised, from narrative to machine-interpretable).

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It is worth mentioning that, given a specific structural choice, the three areas will not necessarily have the same weight in all plans. Specific situations and contexts of use will determine the relative importance assumed by each area and will govern the amount, nature and detail of the information provided for a given aspect of the plan. A few examples will clarify this concept:

- a plan designed for computer-based enactment, as is typically the case with IMS-LD, will not require any *Pedagogical Rationale,* while fully detailed *Specifications* will be of paramount importance;
- a generic plan designed as an exemplary model for reuse in a variety of contexts and subject areas will mostly convey information concerning structure and/or educational strategy, with only light coverage of *Target* or *Specifications*. The use of a plan of this type can be compared to the adoption of a learning pattern (Hernández-Leo et al., 2006);
- a pedagogical plan could be designed as a "germ" to be further elaborated, reworked and instantiated in accordance with the needs of specific contexts. In this case, one area may provide quite detailed data, while others are only partially specified or left completely empty. This may be the case when an author proposes the use of an innovative tool or teaching methodology and wants to suggest basic ideas about how to apply it in practice;
- where inquiry and experiential learning strategies are adopted, the plan's learning activities might be only partially described, in accordance with the contingent nature of such activities and the shift in locus of control towards the learner (Schneider, 2004).

3.2. Hierarchical pedagogical plans

A distinctive feature of the model is that pedagogical plans are organized as hierarchies where each *node* is an elementary plan. This choice derives directly from the main aim of our plan model, namely to enhance communication. The upper nodes in the hierarchy typically provide an abstract and summarised description of a plan, which is especially useful for fostering comprehension and communication. On the other hand, the lower levels, especially the leaves, provide more concrete and detailed information and are the actual entities to be enacted. This organization makes provision for a facilitated path of access to the complexities of a plan, where the many details become understandable in the framework of a small number of general ideas. Of course this implies some redundancy and results in extra work for authors because of the need to describe a plan at different levels of abstraction.

All the plans in a hierarchy share the same structure, i.e. they are all composed of the same three areas (*Target*, *Pedagogical Rationale* and *Specifications*) which in turn exhibit the same organization throughout the whole hierarchy. This is not intended to force plan authors to apply the same scheme of thought everywhere in the hierarchy, but rather to provide them with a *complete* expressive palette. The initial definition of *Target*, *Pedagogical Rationale* and *Specifications* should be broad enough to cover all the expressive needs required of a plan (or a group of plans). Subsequently, in each elementary plan of the hierarchy, the author is free to trim that palette by assigning no value to descriptors considered either to have no meaning locally or to be of no particular use for communication. In this way, as already mentioned, each of the three areas may assume different weights in the different nodes of the hierarchy.

To clarify the concept of the hierarchical pedagogical plan, let us examine a real example taken from the Remath project. This plan is intended to engage students in exploring the mathematical structure of 3D geometrical objects using MaLT, a programmable environment for interactive geometrical simulations in 3D space (Kynigos & Latsi, 2007). Fig. 1 shows the hierarchical structure of the plan. The picture is taken from a screenshot of the Pedagogical Plan Manager (PPM), a prototype tool for building hierarchical plans that is described in Section 4.

It should be noted that the name of the root (Programmable Constructions in 3D Geometrical Space) can be interpreted both as the name of an elementary plan and as the name of the whole hierarchical plan. Here the author has adopted different criteria of refinement at the different levels of the hierarchy. The first level of refinement is mostly content oriented, i.e. all the plans which are children of the root, with the exception of Introduction, are named (and organized) after the content they refer to. At the second level, when refining the Angles in 3D space plan, the author has used a different criterion, highlighting the type of activities that the plan envisages (constructing…, simulating…).

It is interesting to note that the hierarchical link does not imply that all the child plans of a given parent are necessarily activated at enactment time. For instance, the plan Extension: simulating the opening-closing pages of a book, as specified in its detailed description, refers to an optional activity and can be enacted according to teacher choice or student interest.

Since a detailed description of all the plans in the hierarchy would be too lengthy, a sense of the hierarchical organization is provided by showing the values attributed to one specific descriptor throughout the different levels of the hierarchy (Fig. 2). The descriptor in question is cognitive goals (which, in the plan model, is part of Target) and the figure shows the path connecting the root with a leaf of the hierarchy (Programmable constructions in 3D geometrical space > Angles in 3D space > Revolving door simulation > Constructing parallelograms in 2D plane).

The cognitive goals of the plan Revolving door simulation are identical to those of its parent plan (Angles in 3D space) because the author has not considered it meaningful to differentiate or refine them further at that level. So the child node effectively inherits this value from the parent; to support this, the Pedagogical Plan Manager provides an inheritance mechanism, which is described in more detail in Section 4. The text in grey in the figure is inherited from the upper level of the hierarchy.

3.3. Order of enactment

In principle, hierarchical organization does not imply or impose enactment of the component elementary plans in a specific order. However, this does not mean that the elementary plans are to be enacted randomly, since the number of sequences that are meaningful and pedagogically consistent is usually very limited, typically just a few or often only one. Experience with the hierarchical model has shown that both plan authors and users implicitly adopt the *innermost-leftmost* rule[3] as the "natural" criterion for generating an activity sequence from a hierarchy. Strictly sequential enactment is easy to deal with but involves several pedagogical limitations (Janssen, Berlanga, Vogten, &

[3] The *innermost-leftmost* rule is a classical tree visit strategy. It requires starting at the root, assuming that the left edges are chosen before right edges, and assuming that the visit remembers previously visited nodes and will not repeat them. The rule is recursively applied while descending the tree.

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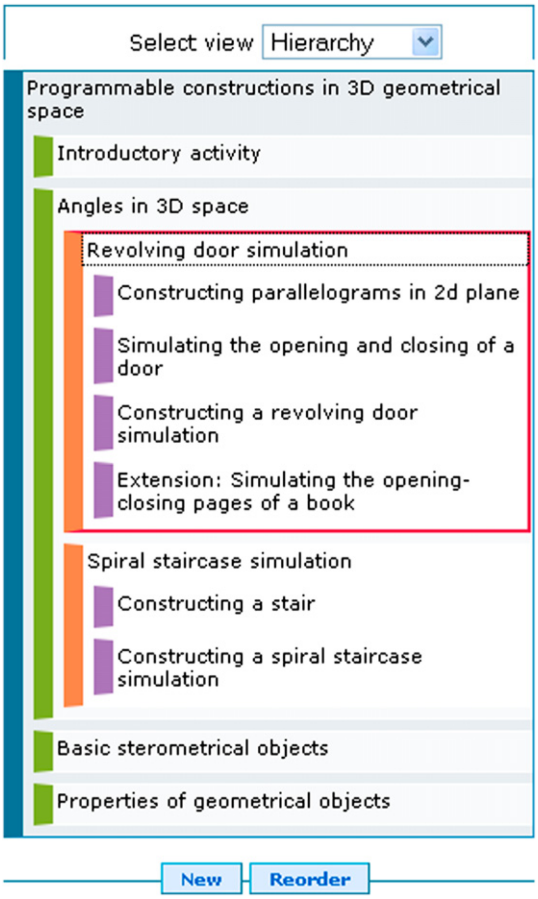

Fig. 1. Hierarchical structure for the pedagogical plan "Programmable Constructions in 3D Geometrical Space".

Koper, 2008) and makes no provision for more complex learning flows. Such flows might be meaningful or necessary for a variety of factors such as:

contingency – which plan is to be enacted at a given time may depend on dynamic conditions whose value cannot be established at design time, e.g. the outcome of another plan, the need to synchronise learners for certain plan activities, the rescheduling of a sibling plan imposed by external factors;
personalisation – learners' individual preferences and characteristics, such as interests, learning styles, abilities/disabilities, call for the provision of options and, possibly, alternative learning flows (Cristea, 2005);
locus of control – approaches that favour active learning and/or involve *minimal guidance* (Kirschner, Sweller, & Clark, 2006), such as inquiry, problem-based or experiential learning, demand that learners have some degree of freedom to choose or build their own learning paths. This requires optionality and potentially complex plan branching.

To overcome the limitations of strictly sequential enactment, the hierarchical model has been enhanced by associating to each collection of *Sibling* nodes, i.e. those which share a common father, a *Network of Enactment* (NOE). A NOE is a graphic schema which encompasses all the possible paths of enactment compatible with the precedence rules existing among the sibling nodes. These conditions may include prerequisite rules, production and subsequent use of artefacts, waiting for specific events, learners' choices, and so on. A formalism for representing NoEs has been defined with expressive power and facilitating power in mind but no experimental data are available yet on NOE use. Fig. 3 is intended to provide a sense of this formalism. It shows the refinement of the plan *Revolving door simulation* (see Fig. 1), which features an optional plan (*Simulating the opening – closing pages of a book*).

4. Pedagogical Plan Manager (PPM): a tool for managing hierarchical plans

Building and navigating hierarchical plans would certainly be a complex and unwieldy task without a specific support tool. So the ReMath project involved construction of the Pedagogical Plan Manager (PPM), a prototype web-based environment which includes an editor for building and modifying plans, a viewer for navigating existing plans and a simple repository facility for managing access to existing plans (Bottino et al., 2008)[4]. To foster interoperability, the PPM is based on an XML plan representation. This prototype implements

[4] The PPM is available at http://ppm.itd.cnr.it. It can be freely used for viewing existing ReMath plans and for creating/editing temporary trial plans.

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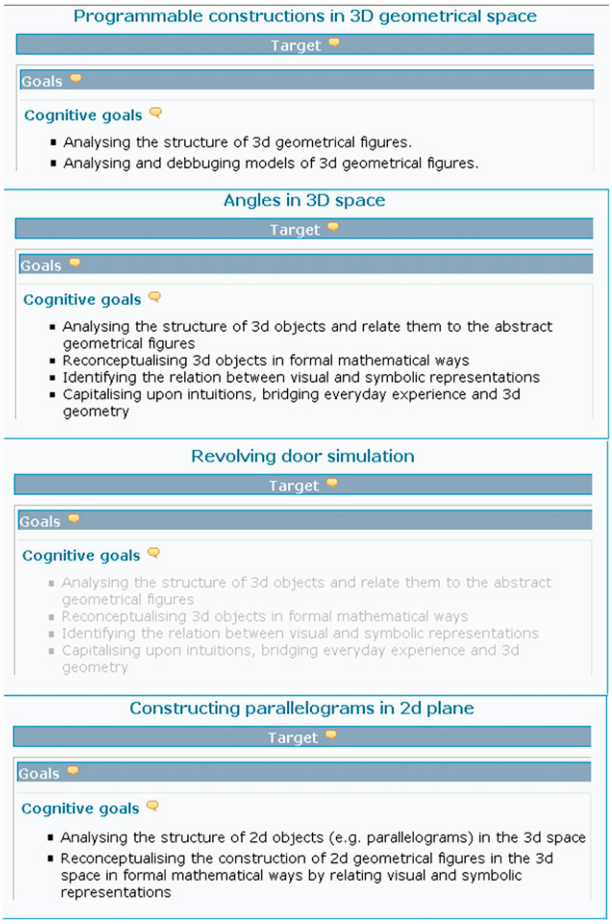

Fig. 2. The values assumed by a specific descriptor (*cognitive goals*) throughout the different levels of the hierarchy.

the pedagogical plan model only partially, in the sense that (1) only linear NoEs are presently allowed and (2) the descriptors used in the model can be customized only by sub-setting the predefined system of descriptors.

The PPM has three main functional components: the Hierarchy Manager, shown in Fig. 1, the Field Selector (Fig. 4) and the Data Area (Fig. 5). The content of the *Data area* depends on (i) the section of the hierarchy selected in the *Hierarchy Manager* and (ii) the fields selected in the *Field Selector*.

The *Hierarchy Manager* located on the left of the screen – see Fig. 1 – shows the current structure of a plan and, at the same time, acts as an editing interface: the new and reorder buttons let the user create new nodes and reshape the structure by dragging individual nodes or whole branches of the hierarchy into a different position. The Hierarchy Manager is also used for selecting the elementary plan or the section of the hierarchy to be visualized and worked on in the *Data Area* (in the case of Fig. 1, the sub-hierarchy Revolving door simulation has been selected). An important component of the Hierarchy Manager is the View Selector (located just above the hierarchy), which provides two options, single node or hierarchy. Single node allows the user to visualize and work on the content of individual elementary plans; with hierarchy, the same can de done with a hierarchy of plans (remembering that a node can be interpreted both as an elementary plan and as the root of a hierarchy). In the case shown in Fig. 1 the View Selector is set on hierarchy.

Using the Structure Manager, the author can quickly select and work on any individual node (plan), on any sub-hierarchy or on the whole hierarchy. Shifting easily from one level of the plan to another is a key factor in supporting different authoring styles. Authors can begin at the topmost abstract level and work their way down, or begin from concrete particulars (say, the details of a learning activity) and develop

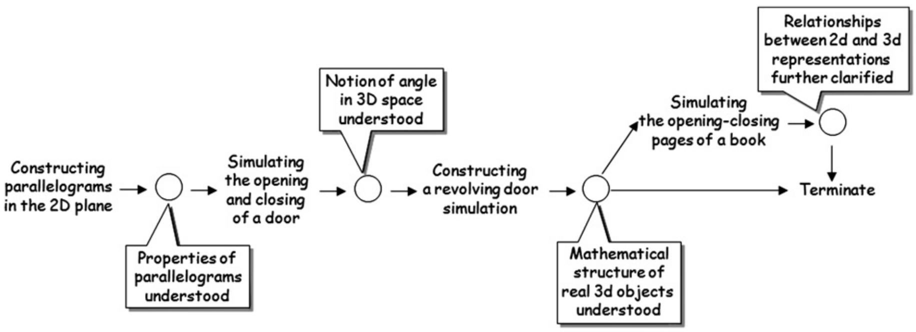

Fig. 3. An example of Network of Enactment with an optional path.

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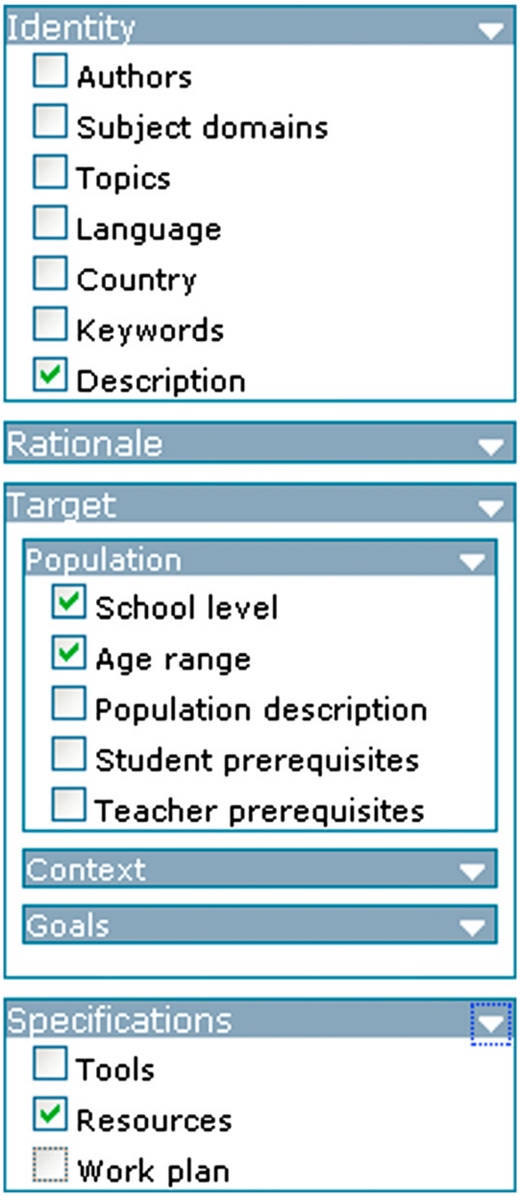

Fig. 4. The *Field Selector.*

their plans upwards, or start at an intermediate level and work outwards. Hierarchical representation combined with flexible visualization supports all of these approaches.

The Field Selector (Fig. 4) lets the user select the descriptors to be displayed and worked on. The example in Fig. 4 shows the *Field Selector* set so that the fields in Rationale are collapsed; other fields such as Resources and Work Plan represent clustered descriptors. The checked descriptors are those displayed in the Data Area. The set of descriptors available in the *Field Selector* in the current version of the PPM is not a fixed feature of the plan model. These descriptors reflect the specific needs of the ReMath project and were established in order to accommodate the very diverse communication requirements of different actors and roles in the project (Earp & Pozzi, 2006).

While designing a new plan, authors can use the *Field Selector* into two different ways:

- as a customizing facility for shaping their plans in accordance with their needs by selecting relevant fields;
- as a support to plan design by helping to switch attention from one group of descriptors to another in the process of following the personal design path.

The Data Area represented in Fig. 5 corresponds to the status of both the *Hierarchy Manager* as shown in Fig. 1 and the *Field Selector* as shown in Fig. 4.

Fig. 5 shows only a small part of the information contained in the *Data Area* (i.e. the field Resources of the plan: Constructing parallelograms in 2d plane); viewing all the nodes and descriptors involved in this case means scrolling up and down. Fig. 5 also shows the field Description of Resource open for editing. Authors can populate the fields in the PPM Data Area with various kinds of descriptive data, such as text, images, links, html code, etc. They can also upload files and digital resources of any type, which can also be used in enactment.

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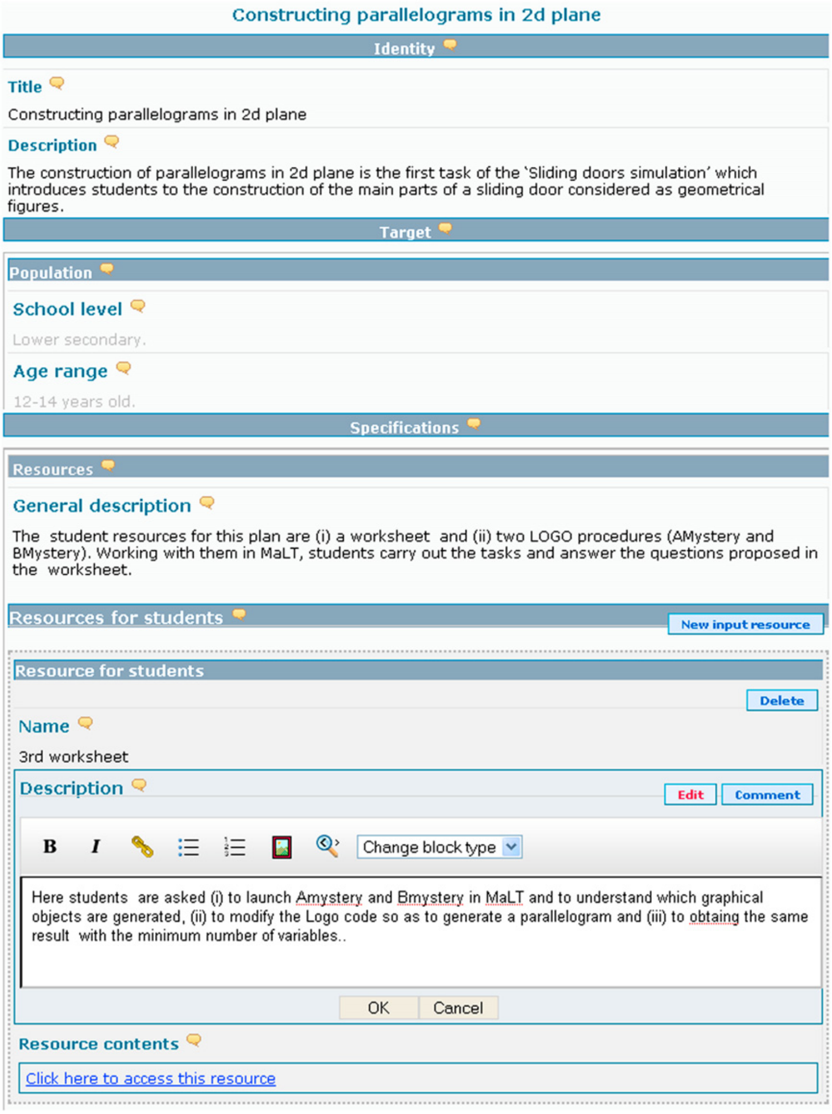

Fig. 5. The *Data Area* – Resources field in the plan Constructing parallelograms in 2d plane.

Combined use of the Structure Manager and the *View Selector* allows the author to quickly choose, visualize and work on any individual node (plan), on any sub-hierarchy or on the whole hierarchy.

Shifting easily from one level of the plan to another is a key factor in supporting different authoring styles. Authors can begin at the topmost abstract level and work their way down, or begin from concrete particulars (say, the details of a learning activity) and develop their plans upwards, or start at an intermediate level and work outwards. Hierarchical representation combined with flexible visualization supports all of these approaches.

An interesting possibility for authors is working on an individual descriptor (or chosen subset of descriptors) at different levels of the hierarchy so as to ensure consistency and suitable refinement. This is done simply by selecting ONLY the desired descriptor/s in the *Field Selector* and choosing a specific (sub)hierarchy in the *Hierarchy Manager*. Fig. 6 shows the field content-epistemological goals selected in the *Data Area* together with the sub-hierarchy Angles in 3D space. In this example the values are still to be assigned and one field is open for editing.

Finally, to facilitate construction of hierarchical plans, an optional top-down inheritance mechanism has been integrated. When filling in a given field at a given level, authors can either attribute a specific value to the field or opt to inherit en bloc all the data from the corresponding field in the immediate parent plan, The lower part of Fig. 6 shows how the assignment of a value to a specific field (content-epistemological goals) takes place. After opening the field, the author chooses between edit and inherit (the comment button lets the author insert a comment on that specific field, which is particularly useful for collaborative authoring). In the example shown, the author has chosen the edit button and the editing window has opened.

The inheritance feature not only reduces the work required for hierarchical plan construction, but also simplifies the task of modifying an existing plan. When a field is edited in a given plan, the changes made automatically propagate to plans lower down in the hierarchy along the chain of inheritance. No provision for upward propagation has been made since this could create more problems than real advantages.

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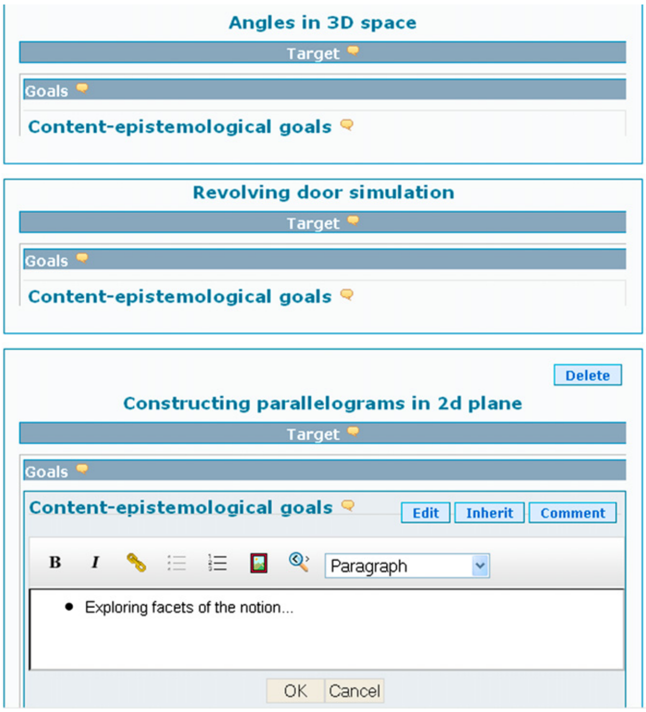

Fig. 6. Working on the same descriptor at different hierarchical levels.

5. Preliminary results from an initial application

The pedagogical plan model and the PPM have been used by six research groups in ReMath to build twelve different pedagogical plans. These plans feature experimental classroom activities using innovative educational software that the teams themselves developed. Each team was in charge of designing and carrying out two different classroom experiments, one using their own software (the so-called "familiar pedagogical plan"), and another using software produced by another team (the "alien pedagogical plan"). These plans evolved through successive versions in response to ongoing experiences with teachers and students and as a result of interactions among the research groups. A total of 45 plans was produced and made available. As already mentioned, those plans were intended as vectors of educational innovation, and the ReMath experimental activity was mainly aimed at evaluating and comparing different theoretical approaches and different educational tools. With respect to this aim, the experimental evaluation of the plan model and of the PPM played an instrumental role and was therefore carried out more as a preliminary evaluation within the project community than as a general experiment.

The process of designing and carrying out the field experiments, referred to in the project as "cross-experimentation" (Bottino, Artigue, & Noss, 2009, pp. 73–87), involved three groups of PPM users: authors, namely the researchers who produced the "familiar" and "alien" plans; readers, i.e. teachers and researchers who read the plans either to understand how a given educational software could be used in school practice, or to decide whether to test a given plan; and experimenters, i.e. researchers and teachers who enacted the plans in the classroom.

In this section the preliminary experimental results concerning the evaluation of the plan model and of the PPM are presented. These are mostly qualitative and derive from two complementary sources:

Existing plans: The existing plans were a direct source of information about the behaviour of authors working with the PPM and their interpretation of the model as embodied in the PPM. Plan analysis was carried out by three observers, who, after agreeing on a set of common criteria and research questions, worked separately.

Questionnaires and interviews: In order to explore users' perceptions of the PPM and the underlying model, two different questionnaires were submitted to authors and to experimenters, while informal interviews were conducted with readers (Bottino, Ott, & Pozzi, 2009).

A third, more informal but rather meaningful source of feedback on the plan model was the behaviour of the participants throughout the project when dealing with or communicating about plans. In the following, the main results of the experiment are reported. These have been organized around a small number of topics representing strengths and weaknesses of the model or specific patterns of behaviour adopted by the different users.

5.1. Impact on communication

The pedagogical plans developed by each ReMath group were mainly (but not exclusively) intended as vectors of the approach to math education adopted by that group. Their aim was to provide a concrete basis for reciprocal understanding, cross-fertilization and, to some extent, integration of the theoretical frameworks adopted by the different ReMath groups. This was to be achieved by first developing and testing a *familiar* plan and – at a second stage – developing and testing an *alien* plan. Thus the plans underwent classroom experimentation intended to answer a variety of research questions, at least partly related to the values and the problems emerging from the *collision* of different approaches. In this framework the main role of pedagogical plans was that of tools for communication. This was especially

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appreciated as a supporting factor for cross-fertilization among the different research groups. Here are some representative statements taken from the questionnaires:

"… the familiar Pedagogical Plans provided strong inspiration for the theme of the alien Plan."
"… Initially, activities in the familiar Pedagogical Plan were examined. Ideas for possible tasks were discussed with the second alien team …"
"… Cross-reference was made with the familiar Pedagogical Plan in the PPM, which also led to further technological development of the DDA[5] …"

Questionnaire responses from the experimenting researchers indicated that they too found the PPM to be an effective support for communication, both with their counterparts and with the experimenting teachers. In addition, they judged the information conveyed by plans to be clear and exhaustive enough for use as a guideline for experimentation in real contexts.

5.2. Impact on authoring

Plan authors judged their experience of using the system to be largely positive. They found that the PPM not only allowed them to convey all the needed types of information (*expressive power*), but also effectively supported the design process by providing concrete support in expressing and bringing into sharper focus their initial ideas.

Specifically, all authors declared that:

- the results obtained with the PPM met their expectations;
- the conceptual model underpinning the PPM was of help to express their ideas (only one author stated that the model was only partially helpful because it was "too fragmentary");
- the main advantages of using the PPM are the ease of shaping and modifying plan structure and the possibility to work at different levels of abstraction;
- using the PPM had maieutic value in helping to clarify and develop initial ideas (only two authors complained about the extra authoring effort required by the hierarchical structure).

One author stated that "during elaboration of the alien PP, the PPM was used as a support for defining and shaping the plan structure, and for checking its completeness and congruency; in these respects the PPM proved highly useful". Similar statements were made by other authors as well.

5.3. The value of hierarchical representation

All the users without exception were satisfied with the hierarchical organization as a method of approaching the design of a new plan and as a way of communicating about an existing plan. This was clearly expressed in the questionnaires and interviews, and was demonstrated concretely by the fact that all the research groups spontaneously adopted hierarchies as instruments for communicating the general aspects of their plans, both internally and externally to the project. The value attributed to the hierarchical model is further underlined by the evolution that the plans underwent (most were produced in 3 or 4 successive versions). All the hierarchies but one were meaningful from the very beginning and many underwent a process of steady improvement from the standpoint of homogeneity and consistency, with an evident increase in their *facilitating power*. This shows that authors quickly recognized the value of the hierarchical organization as a concise way of representing and communicating about pedagogical plans and thus considered it worth their while to keep improving their hierarchies.

5.4. Different authoring approaches supported by the model

For their plan development in the ReMath project, authors were not supplied with specific guidelines on how to build a hierarchy or how to carry out plan design. This made it possible to capture authors' natural behaviour and left the way open for different possible uses of the hierarchical model to emerge. Several aspects were left open to interpretation, including the criteria for the refinement process and for encapsulating new elementary plans, the level of granularity to be adopted, the order to be followed while populating the different nodes and fields of a hierarchy. With regard to refinement criteria (most importantly, what basis to use for generating child plans from the one under refinement), plan analysis revealed three main tendencies:

- *Content-oriented criteria*: In this case refinement is based on contents and/or learning outcomes. The new plans generated by the refinement assumed titles such as "Equality and equivalent notions in treating algebraic expressions and equations" or "Algebraic and polynomial expressions". This choice is not just a matter of the convention adopted for labelling plans but has a deep influence on the plan content. While this was the most common choice, it was not a global one, in the sense that in many plans only some of the elementary plans are content-oriented, while others follow other criteria (see below).
- *Pedagogical pattern oriented criteria*: Here the new nodes emerging from refinement refer to specific didactic or pedagogical functions. Examples of node titles are: "Pre-test", "Assessment", "Familiarization", "Planning", "Discussion", "Collaborative challenge", etc. This is a frequent choice, but it is always a partial one, as in most cases it is blended with the content-oriented approach.
- *Event oriented criteria*: This choice occurs in plans where learning is based on "simulated situations". In these cases, the plan names refer to events or tasks within a particular situation. Examples of names of this type are: "Avoid the spy", "The instruments are broken", "Throwing the ball", etc. This approach always occurs at the lower levels of the hierarchies.

[5] DDA stands for Digital Didactic Artefact and refers to the specific educational tools for mathematics built by the different teams.

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Though all choices were meaningful and justified, it was manifest that choices of type *a*. favour understanding of what a plan is about, and also foster the partial reuse of the plan itself. This gradually became clear to some of the authors, whose hierarchies followed an evolutionary path in the direction of extensive application of criterion *a*.

As to the process followed for populating the hierarchy, no author followed a single approach. They typically blended top-down and bottom-up approaches; in some cases, authors considered the values they attributed to single descriptors at all levels in the hierarchy to ensure consistency throughout. This is borne out in statements made in the questionnaires:

"Following the plan structure, we developed the Identity, Description, Rationale.Description and Theoretical Framework fields "vertically" through the plan from the highest root level right down to the leaves, thus generating a kind of backbone that was laid down before other aspects were fleshed out."

"First we used the PPM to build an initial plan structure consisting of four elementary plans. The IDENTITY and RATIONALE groups of descriptors (considered to express the essence of a plan) were completed, starting from the root and following the plan structure according to a more or less top-down procedure. Subsequently the learning activities were designed in collaboration with the experienced teacher […] who provided inputs for the more concrete aspects described in the area SPECIFICATIONS of each elementary plan. This combination of the top-down and bottom-up approaches could be appropriately called "zigzag" development."

5.5. Building hierarchical plans: author response to the work overload

The value of hierarchical organization perceived by plan authors and confirmed by experimenters was offset by the considerable effort required for plan development. The hierarchical model necessarily entails re-specifying the same information at different levels of abstraction/detail.

All the authors but one considered the amount of effort required for building a plan in the PPM to be *reasonable*. At the same time they suggested that effort could be reduced by reducing the number of descriptors. However, plan analysis revealed that these same authors had not taken up the option of systematically leaving some descriptors blank. Actually, all the authors adopted a personal strategy of workload reduction that combined leaving some descriptors blank at some levels of the hierarchy with use of the PPM's inheritance mechanism (which required only minimal effort). A few typical behaviours are as follows:

Only a few descriptors (such as *Target.Goals*, specifying the different types of goals of a plan) are filled in at all levels and are typically refined at each level according to the required degree of abstraction/detail;
Some descriptors such as the those belonging to *Target.Context* (for describing the physical, institutional, and socio-cultural conditions characterizing the environment where the plan is to be enacted) are filled in at the *root* level and then inherited throughout the lower levels;
Other descriptors such as *Specifications.Workplan*, which contains the practical information for enacting a plan, are enunciated at a very general level in the *root* and then specified in detail only in the *leaves* of the hierarchy.

For other fields such as the *Pedagogical Rationale* no clear pattern of behaviour emerged: some authors filled in these fields at the root level and then inherited them; some preferred to leave them empty at the lower levels; some gave them an appropriate value at all levels. As indicated later in the discussion section, detailed analysis of authors' behaviour has provided useful suggestions for future improvement of the hierarchical model that could result in simplifying the plan authoring process.

5.6. The same plan structure cannot fit the needs of different groups

The plan model used in ReMath was tuned on the needs of researchers who were mostly interested in theoretical and pedagogical reasoning. Because of the very strict limits imposed by the timeframe of the project and by technical restrictions on PPM implementation, it was not possible during experimentation to produce simplified views of the pedagogical plans tailored to the specific requirements of teachers and external readers. Thus readers had to make do with the researchers' view of the plans. This represented a violation of the principle of minimal completeness (in its aspect of minimality) and the interviews with readers revealed degrees of dissatisfaction with the quality of communication. Here is a quotation from an interview with a reader: "… There are a lot of interesting ideas on both sides – theory and practice, but I found them distributed and mixed up along all the plans, so that I found it difficult (probably my fault) to collect and assemble all the key elements which are necessary to put in practice each plan." Similar statements were made by the other readers.

6. Discussion

Some elements for discussion have already emerged together with presentation of the experimental results. This section focuses on topics that deserve special attention in connection with the meaning of the results and the future development of this work. Before examining these topics it is important to underline that the plan model was intended to foster communication among all the different actors involved in ReMath and that the results have mostly been collected in this specific context. Further experiments in different educational contexts are required to generalize these results, and this is part of the authors' present research plans.

6.1. Hierarchical organization in pedagogical planning

Hierarchical organization is certainly the major structural aspect of the pedagogical plan model. The use of hierarchies was found to be helpful in several respects, both as a support for authoring and for communicating a plan. The process of building hierarchies was not undertaken in a strictly linear fashion, proceeding straight from the root to the leaves. In other words hierarchy design is not strictly a top-down process or a bottom-up one for that matter, but is rather a zigzag process; what is important is that the result of this *zigzag* process must be organized hierarchically. Striving for this result leads authors towards a better understanding of their ideas about the plan to be

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built and is the very origin of the maieutic value in using hierarchies. This maieutic value is further enforced by the need to associate the appropriate data at the different levels of the hierarchy. This is again a factor encouraging conceptual clarity, which is good for both plan readers and authors. Finally the possibility to navigate the different levels of a hierarchy is an important factor for mastering the complexity of a plan in all the possible stages of its lifecycle (design, modification, use and reuse). It is worth mentioning that even the actors in ReMath who expressed some criticism of the plans, i.e. teachers and readers, recognized hierarchies as structural frameworks facilitating the process of understanding a plan. At this stage hierarchical organization of pedagogical plans appears to be a powerful thinking tool whose value could go beyond the specificities of the context where the model was tested. As to the application of the model outside of the research context, complexity and effort are clearly critical factors; while going through hierarchically organized information is usually an easy task, achieving conceptually clean top-down organization of information is a complex, non-linear activity requiring time and specific expertise.

6.2. Reducing the effort of designing hierarchical plans

The initial principle that each node in a hierarchy is a plan which is *complete* at its own level of detail had a twofold meaning. The first is that any aspect of a plan should be modulated in accordance with the different levels of the hierarchy (the use of inheritance is to be intended as occasional). The second is that any part of the hierarchy should be reusable – possibly by other authors – to build different plans. This necessarily entailed extra effort in plan development. The different strategies that authors adopted to reduce the design effort provided very useful hints for possible improvements in the plan model that could well lighten the authoring effort. The chief indication is that the authors treated plans differently according to their level in the hierarchy. The three main plan categories were the *root*, the *terminal plans* (i.e. the *leaves* of the hierarchy) and the *non-terminal plans* (i.e. the plans between the root and the leaves). They spontaneously filled in only the descriptors which were really meaningful for each type of node and did not give any consideration to the problem of reusability since this was largely out of the scope of ReMath.

Following the above considerations, the future development of the plan model could be based on the following principles:

- the descriptors that are to be completed in a node (plan) of a hierarchy depend on the plan type (root, terminal, non-terminal);
- reusability of a given sub-hierarchy does not come for free and has to be planned in advance, at design time. Subsequently the root of the reusable sub-hierarchy cannot be considered simply as a non-terminal plan but also as a root;
- only those plans which have the *root* attribute need to be complete, where complete means all their descriptors have been attributed an appropriate value.

6.3. The need for multiple views of the same plan

As already mentioned, the general plan model developed within ReMath was tuned to the specific needs of the researchers participating in the project and subsequently incorporated in the PPM. As a result, plan structure became rather complex because the researchers were interested in all the aspects of a plan, including the underlying theoretical framework, the rationale for choosing given plan goals, the context where the plan was to be enacted, the specification of detailed activities and so on, just to provide a sample of the diverse elements comprising a plan. Teachers and readers, when going through the resulting plans, found them difficult to understand and in some case confusing, while the opinion of researchers was generally very positive. This suggests that, when a plan is to be used by different communities, it is important to feed those communities with different *views* of the same plan. Here the term *view* refers to a restricted version of the *complete* plan, a version obtained either by filtering out descriptors of little interest to the target community or by simplifying the content attributed to a descriptor by excluding part of it. It should be noted that multiple views does not compromise the plan model in any way. It is something that can be dealt with by the plan managing tool, which should make provision for definition of different views and selective access to the different views of a plan. This enhancement of the PPM will be the matter of future development.

6.4. Linear enactment vs. networks of enactment

It has been stated that, in principle, the model can support non-linear enactment of hierarchical pedagogical plans through the specification of suitable Networks of Enactment. However, this feature has not yet been implemented in the first working version of the PPM. Interestingly, throughout all the phases of the ReMath project, none of the groups expressed the need to enhance the PPM so as to make it compatible with non-linear enactments based on choices made either by teachers or by students. The reason for this unexpected outcome has not been fully identified; it may depend on several factors such as the nature of the subject matter, the pedagogical tradition in the area of maths education, concern about compatibility with traditional curricula, or even an effort to keep the pedagogical plans reasonably simple so that they can be efficient vectors of educational innovation. However there is a strong feeling that the transition to non-linear plan design entails carefully reconsidering the approach to a given area of learning, possibly in the direction of student-driven strategies such as inquiry learning. Extension of PPM capabilities to include the definition of Networks of Enhancement is expected to prove useful for exploring the subject of non-liner authoring.

7. Conclusions

A model for pedagogical plans of an “inspirational” nature, specifically oriented to fostering interpersonal communication and supporting plan authoring, has been presented. A preliminary tool (the PPM) that partially implements the model has also been described. The model aims at satisfying three basic requirements considered essential for effective communication, namely expressive power, facilitating power, and flexibility. The model is based on hierarchical organization of pedagogical plans and can be easily adapted to the needs of different user communities, even though this possibility has not yet been fully implemented in the tool. The model was originally tuned on the needs of a community of researchers in technology enhanced learning in mathematics and has been used for three years in the context of

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an international research project. Evaluation of the model's impact was performed by drawing on three different data sources: user questionnaires and interviews; analysis of 45 pedagogical plans developed within the project; and observation of the behaviour of the different actors involved in the project when communicating and reasoning about their pedagogical plans. All these data suggested the value of the model for communication purposes, and its use was an important factor in cross-fertilization among the different groups participating in the project. Appreciation was also expressed about the model's support for plan development; this derives from its capacity to encourage flexible authoring and from its maieutic power, helping authors to clarify their initial ideas and bring them into sharper focus. All the actors involved in ReMath recognized the value of hierarchical plan organization. This was shown by explicit statements expressed in questionnaires, by observation of project activities in which hierarchical plan structures assumed a definite role as communication artefacts and, last but not least, by analysis of plan development, which revealed the considerable effort authors devoted to improving their hierarchies. While these initial results are encouraging, the transfer of the hierarchical plan model from a research project to different contexts requires further investigation and experimental work. Two aspects that need to be explored in particular are the influence of different content areas and the authoring behaviour of different actors, for instance different types of teachers.

To cope with the considerable design effort required by hierarchical organization, authors developed their own effort reduction strategies which, in turn, became the source of ideas for future improvements in both the model and the tool.

The plans developed within the community of ReMath researchers were also used directly with teachers and readers outside the project without any mediation or filtering from a teacher oriented view. Subsequent interviews revealed some dissatisfaction about the resulting information overload imposed on these two actor groups, who were interested more in the practical aspects of a plan than its underlying theoretical frameworks. This highlights the importance of providing different views of the same plan to different categories of users.

Some future developments in this direction have already been discussed. To conclude, it is worth noting some of the other research topics briefly mentioned that are connected with the model. These include model customisation for different groups of users and possible development of related support tools, the behaviour of the model in different situations and for different purposes (transfer of innovation, collaborative plan authoring among teachers, etc), the potential and impact of non-linear plans, and the value of making learners aware of the plan being enacted and letting them participate in further plan definition at enactment time, something that would typically take place with inquiry- exploratory learning strategies. Exploration of these topics will form part of further investigation into the model, the PPM tool, and their potential application within teaching and learning processes.

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