A Framework to Support Social-Collaborative Personalized e-Learning

Maria De Marsico[1], Andrea Sterbini[1], and Marco Temperini[2]

[1] Dept. of Computer Science, Sapienza University of Rome, Italy
[2] Dept. of Computer, Control, & Management Engineering, Sapienza University of Roma, Italy
{demarsico,sterbini}@di.uniroma1.it, marte@dis.uniroma1.it

Abstract. We propose a comprehensive framework to support the personalization and adaptivity of courses in e-learning environments where the traditional activity of individual study is augmented by social-collaborative and group based educational activities. The framework aims to get its pedagogical significance from the Vygotskij Theory; it points out a minimal set of requirements to meet, in order to allow its implementations based on modules possibly constituted by independent e-learning software systems, all collaborating under a common interface.

Keywords: Personalized e-learning, adaptive e-learning, social collaborative e-learning, zone of proximal development, reputation system.

1 Introduction and Motivations

This paper presents a framework for the dynamic configuration of paths of learning activities for both individual and group education. To define such a framework, one main issue is how to personalize the learning pathway according to the learning characteristics of, respectively, individual students and groups, and, going further along this line, how to make such pathways adaptive to the changing assessment of the above mentioned characteristics. The framework should then allow defining courses as learning paths – LP (i.e. sets of learning activities – la) and maintain a model of the student's characteristics relevant to learning. It should allow: to define a learning activity in such a way that collections of *la*s can be stored in repositories and appropriately selected to build a course; to discriminate the *la*s with respect to the learner's (or group's) learning characteristics, so to be able, once stated the aims to be met by a course, to select only what is needed and most appropriate to complete the course *LP*

This in turn requires: to model (represent) the learner's characteristics, such as the possessed knowledge and abilities, and/or the learning style; and to model the characteristics of a group of learners according to the individual ones, such as with the assessment of shared knowledge, or "sharable" knowledge that could determine the group dynamics; at the best of our knowledge, while a lot can be found in literature on how to set up effective group activities, very little is said about the formal relation

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between the kind of activities and the individual characteristics of group components, as well as about how to choose the components of an effective group.

Personalization and adaptivity are very relevant topics in e-learning research. Traditional investigations are on the accommodation of personal-individual study activity (see [1] for wider reference); the coordination of group study work is also a much frequent topic, also for its interconnections with aims different from direct education of students (cfr. [2,3] and see [4] for the use of e-learning technologies in professional group work). Moreover social-collaborative learning is coming to be more often studied, as a next step in motivating and augmenting study activity [5,6].

2 Framework Basics

According to the requirements identified above, the framework allows to map the core features of both the learner and the learning activity on a set of operational items which are exploited during content deployment and for its personalization. We list below the main elements that must be taken into account. Modeling the *Learner* (individual), requires to take into account and represent her/his personal characteristics such as: the skills (knowledge, abilities) achieved; the confidence we can assign to the above achievements, i.e. a measure of how a skill is more or less firmly possessed by the learner, to be compared with the requirements to be met to tackle a specific learning activity; the learning style; reputation gained during activities involving social/group collaborative e-learning It is worth noticing that we are defining here the backbone of the framework, and leaving aside the details about our implementation. For instance, we adopt the Felder-Silverman model (with the well-known *dimensions* active-reflective, sensing-intuitive, visual-verbal, and sequential-global [7-9]). In this way the high-level specification can accommodate different learning-style-qualified versions of the same content; during the delivery of a course, when a *la* is to be presented, the version corresponding to the current evaluation of the learner's learning style can be used. The definition of a model for the learner requires specifying the concept of *skill*. A skill is the representation of an ability/knowledge that can be possessed or pursued. A learning activity is deemed to let a learner acquire certain skills, and often, for the learning activity to be tackled, a set of prerequisite skills is needed. In our framework, a skill is defined as a predicate S() whose arguments state: a *main concept* (a conventional name for the ability or knowledge); an integer value (*level*)and a *keyword*, expressing the cognitive level to which the concept is possessed, according to Bloom's taxonomy [10]; an optional *matching concept* (possibly multiple), to which the achievement of the main one is related (for certain keywords in the Bloom's Taxonomy such matching concepts might be needed for further qualification of the cognitive level); a *context*, stating the disciplinary context in which the concept(s) is intended. In summary, we can speecify a skill as:

S(concept, k, keyword, matchingconcept(s), context)

The predicate expression of skills allows a (limited) set of inferences, such as

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if S(c, 3, use,  c', ctxt) then S(c,2,describe,c',ctxt)
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As for a *learning activity*, we adopt a general declination of the concept of learning object. It is an educational resource deemed to support either individual study (such as the case of a text page with images) or practical activities (such as the solution of an exercise with feedback by the teacher) or some more complex tasks, implying one (or more) group collaborative or social-collaborative learning activity. An activity is characterized as "individual" if its organization and design implies feedbacks, and possibly exchanges, only with the tutor/teacher. Group collaborative activities are based on the collaboration of a small group of learners (e.g. from the same class). Social collaborative activities are based on interaction and exchange among "peers" in a wider set of learners than the group (usually a set of groups, or the whole class, or even, in some advanced settings or during particular activities, participants external to the usual class context, such as users in a web-based Community of Practice – CoP [11,12]). Here the concept of reputation can get significantly into the framework [13,14], as a means to update the individual learner model according to her/his performance during learning activities in a social-collaborative environment.

In the proposed framework the components of a learning activity *la* are defined by the *la* designer (an expert in the learning domain) and are the following:

- *la.Content* – a collection of learning material, allowing the execution of an instructional process, possibly by the use of a supporting software platform: a web page containing the text to study, can be handled by a browser; an interactive exercise can be programmed and presented as a flash clip; a group activity can be performed via web through an accordingly programmed software system (Content Management System – CMS); a social collaborative learning activity can be performed in another dedicated web system, e.g. a CoP platform. In the la, for such material different versions should be comprised, according to different learning style to match for the students.
- *la.A* – Acquisition: a set of skills, whose achievement is expected after the *la* has been successfully tackled
- *la.P* – Prerequisites: a set of skills that are "needed" before being ready to fruitfully tackle the *la*.
- *la.Effort* – a quantification of the cognitive load associated to tackling the *la*.

Completing a *la* will take to the integration of *la.A* into the set of skills possessed by the student, with a *confidence* which depends on student's performance in, e.g., a final test, as we will see below. A repository of learning activities is a set of *la*s available to build courses on a given subject. We include in the repository those activities for which *la.A* is included in the power set of *H*, which is in turn the full set *H* of skills related to a certain subject:

$$R=\{la \mid la.A \in \wp(H)\}$$

Notice that *la.P* may intersect $\wp(H)$, but it may contain concepts from other subjects as well (for example physics theories require knowledge of mathematics). It is up to the course designer to include also related learning activities in the course.

We define a *learning path* as a set $LP=\{la_i\}_{i \in \{1...n\}}$. For a *LP* we can state the overall acquirements *LP.A*, and the overall requirements *LP.P* as

$$LP.A = \cup_{i\in\{1...n\}} la_i.A \qquad\qquad LP.P = \cup_{i\in\{1...n\}} la_i.P \setminus LP.A$$

and the overall effort imposed by *LP* on a learner as $LP.Effort = \sum_{i\in\{1...n\}} la_i.effort$

A course personalized for the learner *l*, is a learning path built basing on a student model of *l*. A *student model* represents the current evaluation of the individual learning characteristics, relevant for the learning process implemented by course tackling; the student model of *l*, SM(*l*), has to be continuously updated during course, to reflect the changes (evolution) of *l*'s learning characteristics determined by the learning activities; such updates, in turn, are used to modify the course path and/or presentation themselves, having them adapting to the above mentioned evolution.

As already sketched above, a basic definition of SM(*l*) spans over

- *l*'s learning style (that is the *current evaluation* of her/his learning style: *LS(l)*)
- *l*'s state of skills, that is an informative representation of the set of skills that *l* is *currently possessing*, *SK(l),* which is upgraded as the student tackles learning activities: $SM(l) = \langle LS(l), SK(l)\rangle$

Here, *SK(l)* is more than just a list of skills: it represents both the skills possessed and the degree of trust (*certainty*) we can put on that. So it is a set of *qualified couples*

$$SK(l) = \{\langle s_1, c_1\rangle, \ldots, \langle s_{nl}, c_{nl}\rangle\}$$

where each c_i is the "certainty of possession", for the associated skill s_i.

The certainty of possession for a skill is a number $c\in[0...1]$: an higher certainty corresponds to greater confidence in the possession of the skill. The certainty is computed according to the assessment activities undertaken by the learner during the course: when (for example after having answered to multiple choice questions) the skill *s* is considered as acquired by the learner *l*, the couple $\langle s, c_{ENTRY}\rangle$ is added to *SK(l),* where c_{ENTRY} is a suitable default confidence; after a further successful assessment for *s*, the certainty is updated to witness an increasing trust in the actual achievement of the skill; on the other hand, if a further assessment activity on *s* is unsuccessful, the certainty decreases. In this way, at any moment the state of skills for *l* shows the current evaluation of certainty for the achieved skills. Notice that iterating the assessment process beyond certain limits would not be sensible: when the certainty for *s* decreases below a level c_{DEMOTE} the couple $\langle s, c\rangle$ is extracted from *SK(l)*: the skill is not actually possessed and further study activity will be needed to acquire it back; on the contrary, when *c* in $\langle s, c\rangle$ climbs above a conventional value $c_{PROMOTE}$, the skill is to be considered firmly acquired, and further assessment for it will not be necessary anymore. We remind that for a student *l* to be considered able to access a certain activity, all skills in *la.P* should be present in *SK(l).* In the framework, c_{ENTRY}, c_{DEMOTE}, $c_{PROMOTE}$ have no predetermined value; as for our implementing system [8], we set some defaults for them (resp. 0.6, 0.35, 0.8), but allow the teacher to assign them differently, according to preferences related to the nature of the repository used, or even of the courses to build. *Course configuration* is the activity of construction of a learning path (a course) according to the student's state of skills and to her/his formative aims on the subject at hand. We define, for the set $SK(l) = \{\langle s_1, c_1\rangle, \ldots, \langle s_{nl}, c_{nl}\rangle\}$, its *s-projection* as the set of skills appearing in the qualified couples:

$$s\text{-}proj(SK(l)) = \{s_i, \text{ with } \langle s_i, c_i\rangle \in SK(l)\} = \{s_1, \ldots, s_{nl}\}$$

We also define

- the starting knowledge of *l*, with respect to the course to build, as the initial value of the state of skills $SK(l)_{INIT}$; this may result, for example, from a precourse assessment activity, stating that a certain set of skills is possessed with certainty at least C_{ENTRY}; in a similar way, $SK(l)_{FINAL}$ is the state of the student's skills at the end of a course
- the formative aims of *l* in tackling the course as the set of skills that *l* is expected to possess, with certainty at least $C_{PROMOTE}$, after taking the course (it may happen that certainty for certain skills continue to increase beyond CPROMOTE thanks to related activities, but in this context it is not deemed significant to continue measuring such increase)

$$T[l] = \{s_1, \ldots, s_{ml}\}$$

Then a course configuration for *l*, with starting knowledge $SK(l)_{INIT}$ and formative target *T[l]* is a learning path $LP(l, T[l]) = \{la_1, \ldots, la_{tl}\}$ such that its learning activities, together with the initial state of skills can cover the formative needs:

$$\{<s_i, c_i> \mid s_i \in s\text{-}proj(SK(l)_{INIT}) \wedge c_i = C_{PROMOTE}\}$$
$$\cup$$
$$<s_j, c_j> \mid s_j \in LP(l, T[l]).A \wedge <s_j, c_j> \in (SK(l)_{FINAL}) \wedge c_j = C_{PROMOTE} \}$$
$$\supseteq$$
$$\{<s_p, c_p> \mid s_p \in T[l] \wedge c_p = C_{PROMOTE} \}$$

A course is considered successfully taken once

$$\forall s \in T[l],\ <s, c> \in SK(l)_{FINAL} \text{ with } c \geq C_{PROMOTE}.$$

In other words the course *can allow* to have SK(*l*) eventually evolving to contain all the skills specified by T[*l*], with *firm certainty* (at least $C_{PROMOTE}$). The definition of learning activity implicitly allow ro define a *Relation of derivation* (propedeutics): Given two learning activities *la*, $\underline{la}$, if $la.A \cap \underline{la}.P \neq \emptyset$, some skills needed to take $\underline{la}$ are acquired through *la* and *la* precedes $\underline{la}$. This induces a relation of partial order in the repository R, that allows to depict it as a graph of learning activities.

Every course is a subset (subgraph) of R. When we want to present the learner with a sequence of learning activities to tackle, the course built by configuration can be linearized in such a way to comply with the relation of derivation. Such linearization is usually not unique: there can be many equivalent sequences coming from the same LP. Moreover, assigning the learner with a LP where the order of *la*s to take is too strictly predetermined, even when not necessary, may hinder learner's independence and motivation in attending the course. In addition, the framework aims to let the learner live and interact in a social–collaborative e-learning environment, and it is expectable for the "next learning activity" in the course to be selectable by the learner as freely as possible (according to her/his interest, motivations and opportunities). Of course, in order to avoid useless frustrations to the learner, such freedom should be bound by the "affordability" of the learning activity for her/him. This can effectively substitute a prior sequencing. In practice, the choice of the next learning activity should better be limited only by the actual possibility to tackle it, computed according to the current state of skills *SK(l)*. The Vygotskij theory [15] is a rich source of support for the student-system co-evolution pattern depicted above, and is well equipped to provide support to a truly social-collaborative approach to taking learning paths.

3 Enrichment of the Student Model

Given a learner *l*, working on the configured course $\underline{LP} = LP(l, T[l]) = \{la_1, \ldots, la_{tl}\}$, we can define some significant cognitive areas related to student's learning state as follows. The area of Autonomous Problem Solving (APS) is the area of firm knowledge in the present state of skills:

$APS(l) = \{s \mid \langle s, C_{PROMOTE} \rangle \in SK(l)\}$. Where of course, $APS(l) \subseteq s\text{-}proj(SK(l))$.

Basing on SK(*l*) and APS(*l*), the Zone of Proximal Development (ZPD) for the learner can be computed at least as

$$ZPD(l) = s\text{-}proj(SK(l)) \setminus APS(l)$$

This is a zone where the learner has no firm achievements yet, but that can be explored with some help by the teacher or by peers. The area of Unreachable Problem Solving (UPS) can be defined as a consequence, and is the area of the course where it is not safe for the learner to enter, given the present level of skills.

$$UPS(l) = \underline{LP}.A \setminus (APS(l) \cup ZPD(l))$$

At any moment the student model can be determined as

$$SM(l) = \langle LS(l), SK(l), APS(l), ZPD(l) \rangle$$

Actually, the ZPD can be defined in a more challenging way, which may better stimulate the student. The derivation of the new definition follows. Given a learning path $\underline{LP}$, its knowledge domain is $KD(\underline{LP}) = \underline{LP}.A \cup \underline{LP}.P$.

In particular, $KD(\underline{LP}) \setminus s\text{-}proj(SK(l))$ is the set of all skills in the course knowledge domain, that are not yet acquired in SK(*l*). Such skills belong neither in *APS(l)* nor in *ZPD(l)* (as per the current definition of ZPD). Given one of such skills, *s*, we define the set of possible (sub)learning paths *LP'* in $\underline{LP}$, that can eventually allow to acquire *s*, and that are traversable starting with the current state of skills (without losing generality we assume that each subpath is a propedeuticy-ordered set of learning activities):

$$Reach(s, SK(l), \underline{LP}) =$$
$$= \{G=\{la_i\}_{i \in \{1 \ldots nG\}} \subseteq \underline{LP} \mid s \in la_{nG}.A \wedge G.P \subseteq s\text{-}proj(SK(l)) \cup G.A\}$$

Notice that the last condition relating G.P to G.A expresses the possibility that the prerequisites of some $la_i \in G$ might be acquired through a previous $la_j \in G$.

The distance of *s* from the present SK(*l*) is defined as $D(s, s\text{-}proj(SK(l)), \underline{LP}) = \underline{G}.Effort$, where $\underline{G}$ is an element of minimal overall effort in $Reach(s, SK(l), \underline{LP})$.

The set *Support*(s, SK(*l*), LP) = G.P∩ *s-proj*(SK(*l*)) denotes the skills already possessed by the learner that are necessary to reach *s* along a minimal-effort path in LP. We designate such a set as the *support set* to reach *s*. It is reasonable to think that the higher is the certainty associated to the skills in the support set, the better we could expect the learner to reach *s*. Likewise we may think that certainty in the support set can provide an estimate of how far from the SK(*l*) we can go trying to acquire new skills, with reasonable expectations. In other words, the level of certainty in the support set needed to reach *s*, can allow to assess how far in terms of D(), *s* could at most be, and yet still consider *s* in the ZPD(*l*). Actually, D() represents a measure of effort; however the concrete possibility for the student to achieve a certain skill does not only depend on the required effort, yet also on the certainty of the elements possibly supporting such achievement. In other words, supposing that D(s, *s-proj*(SK(*l*)), LP) ≥ D(s', *s-proj*(SK(*l*)), LP) while the overall certainty of the *Support(s, SK(l), LP)* is higher of *Support(s', SK(l), LP)*, we can assume that s might be reachable while s' might not, in spite of a closer distance. So, given the following definitions

$$A1 = AvgEffort(\underline{G}, Support(s, SK(l), \underline{LP})) = \textstyle\sum_{la \in \underline{G}} la.effort / Card(\underline{G})$$
$$A2 = AvgCertainty(Support(s, SK(l), \underline{LP})) = (\textstyle\sum_{<s,c> \in Support(s, SK(l), LP)} c) / Card(Support(s, SK(l), \underline{LP}))$$

the "daring threshold" is the distance from SK(*l*) below which to accept that *s* is in ZPD(*l*), and is defined as *DTreshold*(s, SK(*l*)) = (A2/A1) · *dF,* dF being the daring factor, an integer that is to be configured by the teacher, depending how far from the initial skills it is admissible to go (a multiplicative factor). Then

$$ZPD(l) = \{s \in KD(\underline{LP}) \setminus APS(l), \text{ such that } D(s, s\text{-}proj(SK(l)), \underline{LP}) \leq DTreshold(s, SK(l))\}$$

4 Group Activity

The main problem with group activities is selecting a LP suitable to let the group skills grow according to the individual characteristics of the group members.. This translates in the problem of consistently determining the overall group's state of skills (Group Knowledge - GK), and ZPD, basing on the individual ones. In principle, the group's ZPD should be the largest possible, so to maximize members' gain from the collaborative activities. On the other hand it may also include activities that are outside of some group member's ZPD provided they are not too far away. This is crucial to avoid leaving members behind. A first possible choice is to comprise the skills that are shared by all group members (the intersection of their SKs); this set would represent the minimal shared ZPD and would be bounded on the weakest members: the effect of (bottom) outliers on the group ZPD would be exalted, probably reducing motivation of the "smarter" participants. Moreover this choice would strongly limit the possibility of leveraging the support that could come from more experienced peers, which is a key feature in Vygotskij's model. On the other hand, the dual choice of building the group's GK as the union of all members' SKs, resulting in a maximal group ZPD, would obtain similar negative results as above: it would satisfy the brightest group members (top outliers), and leave the others behind. A mediated solution could satisfy both weaker and brighter students: we compute the group's GK as the union of the members' SK, where each skill has group-certainty equal to its average certainty in the members' SK, so to measure the confidence in the achievement of the skill by the group members. This model could better motivate brighter students to help their weaker peers; in addition it allows expanding the group ZPD, to encompass further, possibly more interesting, activities.

Let ST be a group of students, and LP its learning path. Let's start defining the APS for such group. An obvious choice would be to extend the definition of a student's personal APS, and say that the group-APS should represent the set of those skills that are firmly possessed by all the members of the group. Therefore:

$$APS(ST) = \cap_{l\in ST} APS(l)$$

However, this definition would ignore the possible group reciprocal support in a *group-autonomous* achievement. As for the APS of the group, we might consider a "pseudo-intersection" involving also the possession of knowledge in the individual SKs: skills that are not firmly possessed by *all* members are included in the *APS(ST)* iff they are in *APS(l')* for *some* $l'\in ST$ and they are in *SK(l)* for all the other members $l\in ST$. In this respect, we define a lower threshold τ_C for such certainty, which is:

$$\tau_C = C_{PROMOTE} - C_{ENTRY}/2$$

The *l* students above will support the *l' ones*; so they have to be sufficiently many to allow for the above calculated APS being reliable: suppose we state that there must be at least one of such group leaders for every *g* members in ST, where g is chosen by the teacher according to the activity, then we can say that *from a group viewpoint* the knowledge is "sufficiently firmly" possessed if in the set

$$\text{APS(ST)} = \{s\in \cup_{l\in ST} APS(l) \mid \forall l\in ST(<s,c>\in SK(l)\wedge c\geq\tau_C) \wedge Card(\{l'\in ST \mid <s,c>\in SK(l')\wedge c=C_{PROMOTE}\})\geq Card(ST)/g\}$$

The GK is defined basing on the members SKs as well: it comes out, reasonably, to be an expansion of APS(ST)

$$\text{GK(ST)} = \{<s,c> / \forall l\in ST\ (<s,c_l>\in SK(l) \wedge c=((\textstyle\sum_{l\in ST,\ <s,cl>\in SK(l)} c_l\ ) / Card(ST))\}$$

We use *GK(ST)* and *APS(ST)* to compute *ZPD(ST)*. Instead of direct construction we use a reverse strategy and define implicitly the group ZPD, through criteria of *admissibility* of activities. Two conditions are defined, by working on the *APS(l)*s the *ZPD(l)*s, and the SKs of the group members.

The first condition expresses requirements both on the group composition and on the selected activities; so it is divided in two parts. The group's member's (firm) starting points (APSs) must have some common intersection, and, in addition, the union of the starting points must allow the group to fulfill the activities prerequisites. So, given a group of students ST and a learning path LP, 1) *the group members must share a common portion of APS, and 2) each activity prerequisites is firmly possessed by at least one of the members*: $\cap_{l\in ST} APS(l)\neq\varnothing \wedge LP.P\subseteq \cup_{l\in ST} APS(l)$

The second condition states that students in a group ST must share some common proximal development, and that an activity $la\in LP$ is admissible for ST iff, though possibly being off the ZPDs of some members, it is *not too distant* from them, and it is comprised in the ZPD of at least a number of members sufficient to support the others - τ is a threshold to establish admissibility, for learner *l*, of an la not in ZPD(l):

$$\bigcap_{l\in ST} ZPD(l)\neq\varnothing \;\wedge\; \forall la\in LP\; \forall s\in la.A\; \forall l\in ST \quad \mathrm{D(s, ZPD(}l\mathrm{), LP)} < \tau$$
$$\wedge\; \forall la\in LP\; Card(\{l\in ST \mid la.A\subseteq ZPD(l)\})\geq Card(ST/g)$$

Where *g*, as above, represents the number of students which can be driven by a peer, and can be set by the teacher. Notice that if we used APS in place of ZPD, in the definition of the second condition, we would have some of the brighter members of the group left without anything new to learn in the admissible activities, which makes them useless for them besides, of course, dramatically decreasing their motivation.

Being τ a threshold controlling the span outside individual ZPDs, i.e. beyond the daring zone for the individual learner, one way to set it is to choose the minimum daring threshold for the skills in *la.A*.

Whatever is the chosen strategy, different groups may have different degrees of compatibility and suitability: compatibility among the members can affect the way the members interact and help each other, and in turn, get results out of such collaboration (results in terms of knowledge acquired, more or less firm). Compatibility could be considered with respect to several aspects: here we consider only the aspects related to the knowledge possessed by the students, i.e. the personal SK of the group members.

5 Conclusions

Personalized and adaptive e-learning is widely studied and show its applications in a variety of educational fields [16-19]. We have presented the definition of a framework devised to support the conjugation of learning activity based on individual study and group/collaborative activity in an environment of personalized and adaptive e-learning. Two main characteristics of this work are 1) in the fact that it is detached by any present implementation of actual systems for social-collaborative and traditional e-learning: we have in fact abstracted the framework from previous experiences that are based on existing systems; 2) that the framework is deemed to provide a ground layer for an interface based on the pedagogical principles of the theory of Vygotskij, by designing the formal bases for the implementation of concepts such as the Zone of Proximal Development in an e-learning setting.

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