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School of Pure and Applied Sciences

# Teachers as designers of adaptive learning

A thesis submitted in partial fulfillment

for the degree of Doctor of Philosophy

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**Abstract**: The cornerstone premise of this dissertation is that teachers are the primary change agents of an educational system. Another basic premise is that teachers adapt their lessons with or without the use of technology. Based on these premises, the dissertation extends the notion of teachers as designers to teachers as designers of adaptive e-learning. The role of teachers as designers of adaptive e-learning herein is twofold. They served as co-designers of adaptive e-courses aiming to help students overcoming the inherent difficulties of the subject matter. Also, they served as co-designers of a user-friendly digital environment for adaptive e-learning. The design of such an environment is still considered an open research issue.

The dissertation discusses how the teacher's wisdom of practice can support the adaptive e-learning process. My methodology is based on two theories: a domain-specific learning design theory in mathematics and a generic model derived from curriculum studies. A roadmap on designing adaptive e-courses is proposed focusing on the active role of the teacher in the design process. It is based on conceptual mappings between the design-based research steps and the phases of the theories used to orientate the design process. The research helps the reader better understand teachers as designers of adaptive e-Learning. Also, it reports empirical findings derived from five classroom interventions that investigated how the exploitation of a specific adaptive e-learning strategy that was shaped during the research can assist students to overcome the inherent difficulties of the content to be taught. Also, parameters of students' profile are associated with students' performance gains. More specifically, for the students that followed e-courses which incorporated the adaptive e-learning strategy, I investigated associations between students' prior knowledge, students' age and students' motivation on the domain with the gain scores. The findings indicate that the students that followed the adaptive e-courses performed significantly better compared to the students that followed the non-adaptive e-courses. No significant differences on the gain scores between the different student age groups or student groups with different motivation levels were identified. On the contrary, in the question "were the adaptive learning interventions more beneficial for students with low pretests scores?", the answer is positive.

Also, I examined the questions: a) how can we design a learning environment for adaptive e-learning in a user-centered way?, b) how can we prioritise the design requirements of a digital

environment in a user-centered way? The work described in the previous paragraphs provided insight to question (a). In order to design a user-friendly environment for adaptive e-Learning, a scenario-based requirements engineering approach was adopted. The whole design process was participatory and iterative since it contained three cycles of requirements specification and validation. The final product of the process was a set of user interface mockups along with their accompanying descriptive texts. With respect to eleven key parameters concerning the design of the environment, the final product received very satisfactory evaluation scores among the participants. Also, the ensuing design met at a great extent the expectations of the participants. With respect to question (b), the research introduces the exploitation of the Qualitative Comparative Analysis, as a method to prioritise requirements in the design of a digital environment.

**Περίληψη**: Μία κυρίαρχη παραδοχή αυτής της διατριβής είναι ότι οι εκπαιδευτικοί είναι οι βασικοί φορείς αλλαγής ενός εκπαιδευτικού συστήματος. Άλλη μία βασική παραδοχή είναι ότι οι εκπαιδευτικοί προσαρμόζουν το μάθημά τους με ή χωρίς τη χρήση της τεχνολογίας. Με βάση τα προαναφερθέντα, η διατριβή επεκτείνει την έννοια του εκπαδευτικού ως σχεδιαστή σε αυτήν εκπαιδευτικού ως σχεδιαστή προσαρμοστικής μάθησης. Ο ρόλος των εκπαιδευτικών ως σχεδιαστές προσαρμοστικής μάθησης εδώ είναι διττός. Καλύπτει τον ρόλο του εκπαιδευτικού ως συν-σχεδιαστή μαθημάτων προσαρμοστική μάθησης τα οποία στοχεύουν  στην εξάλειψη των εγγενών δυσκολιών που ενέχει το προς μελέτη αντικείμενο. Επίσης, καλύπτει το ρόλο του εκπαιδευτικού ως συν-σχεδιαστή ενός χρηστο-φιλικού ψηφιακού περιβάλλοντος για προσαρμοστική μάθηση μέσω υπολογιστή. Ο σχεδιασμός ενός τέτοιου περιβάλλοντος ακόμα παραμένει ένα ανοικτό ερευνητικό ερώτημα.

Η διατριβή συζητάει το πώς η πρακτική σοφία του εκπαιδευτικού μπορεί να υποστηρίξει τη διαδικασία της υποστηριζόμενης από τον υπολογιστή προσαρμοστική μάθηση.  Η μεθοδολογία μου βασίζεται σε δύο θεωρίες: μια θεωρία εκπαιδευτικού σχεδιασμού που εστιάζει στα μαθηματικά και ένα γενικό μοντέλο που προέρχεται από το πεδίο της μελέτης αναλυτικών προγραμμάτων. Επιχειρείται μία πρόταση σχεδιασμού μαθημάτων υποστηριζόμενης από υπολογιστή που εστιάζει στον ενεργό ρόλο του εκπαιδευτικού στη διαδικασία σχεδιασμού. Βασίζεται σε εννοιολογικές συσχετίσεις ανάμεσα στα βήματα της βασισμένης στη σχεδίαση έρευνας και των φάσεων των δύο θεωριών που χρησιμοποιήθηκαν για τον προσανατολισμό της διαδικασίας σχεδιασμού. Η έρευνα βοηθάει τον αναγνώστη να καταλάβει καλύτερα τους εκπαιδευτικούς ως σχεδιαστές προσαρμοστικής η-μάθησης. Επίσης, αναφέρει εμπειρικά αποτελέσματα που προέρχονται από πέντε παρεμβάσεις που διεξήχθησαν στη σχολική τάξη και οι οποίες διερεύνησαν το πώς μία συγκεκριμένη στρατηγική προσαρμοστικής μάθησης υποστηριζόμενη από υπολογιστή βοήθησε τους μαθητές να ξεπεράσουν τις εγγενείς δυσκολίες του προς μάθηση περιεχομένου. Η στρατηγική αυτή διαμορφώθηκε κατά τη διάρκεια τούτης της έρευνας. Επίσης, επιχειρήθηκε συσχέτιση του προφίλ των συμμετεχόντων στην έρευνα μαθητών με τη βελτίωση στην απόδοσή τους. Πιο συγκεκριμένα, για τους μαθητές που έκαναν τα προσαρμοστικά μαθήματα διερευνήθηκε αν υπάρχουν συσχετίσεις ανάμεσα στην πρότερη γνώση τους, την ηλικία τους και το μαθησιακό κίνητρο που έχουν με το προς μελέτη αντικείμενο

με την βελτίωση της επίδοσής τους. Τα ευρήματα της έρευνας καταδεικνύουν ότι οι μαθητές που ακολούθησαν τα προσαρμοστικά μαθήματα απέδωσαν σημαντικά καλύτερα από αυτούς που ακολούθησαν τα μη-προσαρμοστικά μαθήματα. Δε βρέθηκαν σημαντικές διαφορές στη βελτίωση της επίδοσης ανάμεσα στις ομάδες των μαθητών που είχαν διαφορετική ηλικία ή που είχαν διαφορετικά επίπεδα κινήτρου ως προς το μελέτη αντικείμενο. Αντιθέτως, σημειώθηκε μεγαλύτερη βελτίωση στην επίδοση στην ομάδα των μαθητών που είχε χαμηλά επίπεδα πρότερης γνώσης.

Επίσης, εξετάστηκαν τα ερωτήματα: α) πώς μπορούμε να σχεδιάσουμε ένα μαθησιακό περιβάλλον για προσαρμοστική μάθηση μέσω υπολογιστή με έναν χρηστο-κεντρικό τρόπο; β) πώς μπορούμε να ιεραρχήσουμε τις σχεδιαστικές προδιαγραφές ενός ψηφιακού περιβάλλοντος με έναν χρηστο-κεντρικό τρόπο; Η εργασία που περιγράφεται στις προηγούμενες παραγράφους αποτέλεσε πηγή γνώσης για το ερώτημα (α). Για να σχεδιάσω ένα χρηστο-φιλικό περιβάλλον για προσαρμοστική μάθηση υποστηριζόμενη από υπολογιστή, χρησιμοποίησα μια μέθοδο μηχανικής απαιτήσεων που βασίζεται σε σενάρια. Η όλη διαδικασία σχεδιασμού ήταν συμμετοχική και επαναληπτική δεδομένου ότι περιείχε τρεις κύκλους προσδιορισμού και επικύρωσης προδιαγραφών. Το τελικό προϊόν της διαδικασίας ήταν ένα σύνολο διεπαφών χρήστη μαζί με τα συνοδευτικά περιγραφικά κείμενα για κάθε διεπαφή. Σε σχέση με έντεκα βασικές παραμέτρους που αφορούν στο σχεδιασμό του περιβάλλοντος το τελικό προϊόν πήρε πολύ ικανοποιητικούς βαθμούς στην τελική αξιολόγηση. Επίσης, η σχεδίαση ικανοποίησε σε μεγάλο βαθμό τις προσδοκίες των συμμετεχόντων στην έρευνα. Όσον αφορά το ερώτημα (β), αυτή η ερευνητική εργασία εισάγει την χρήση της Ποιοτικής Συγκριτικής Ανάλυσης, ως μέθοδο προσδιορισμού κρίσιμων παραγόντων επιτυχίας σχεδιασμού ενός ψηφιακού περιβάλλοντος.

**Ευχαριστίες**

Η ερευνητική δραστηριότητα του 21ου αιώνα δεν μια μοναχική πορεία όπου ο ερευνητής πασχίζει να βρει την αλήθεια κλεισμένος μέσα στο εργαστήριό του, αλλά ένα ταξίδι κατά το οποίο ο ερευνητής (αυτο)προσδιορίζεται συνεχώς καθώς συνεξαρτάται με τους ανθρώπους και αλληλεπιδρά με την τεχνολογία. Σε αυτό το ταξίδι βρήκα αρκετούς φίλους.

Θα ήθελα να ευχαριστήσω τον επιβλέποντά μου, κύριο Θανάση Χατζηλάκο, που μου έδειξε αυτόν τον δρόμο αλλά και τη σημασία που έχουν χαρακτηριστικά όπως η κριτική σκέψη, η επιστημονική εξωστρέφεια, η εμπάθεια, η αυτενέργεια και η αντι-συμβατική σκέψη στην ποιότητα της ερευνητικής δουλειάς.

Ακόμα, θα ήθελα να ευχαριστήσω τον συνεπιβλέπων μου, κύριο Δημήτρη Καλλέ για τα σχόλιά του, την καθοδήγησή του και την πάντα εποικοδομητική, δίκαιη και καλοπροαίρετη κριτική του. Τον συνεπιβλέπων μου κύριο Αντρέα Γρηγοριάδη για τις εύστοχες και πολύτιμες συμβουλές του σε μεθοδολογικά θέματα που αφορούν στην εκπόνηση μιας διδακτορικής διατριβής γενικά, αλλά και σε θέματα που αφορούν μηχανική απαιτήσεων ειδικότερα. Την κυρία Χαρούλα Αγγελή για όλα όσα μου έχει μάθει για την μεθοδολογία εκπαιδευτικής έρευνας και για την προστιθέμενη αξία της εκπαιδευτικής τεχνολογίας, καθώς για τις συζητήσεις μας σε σχέση με αυτά. Την κυρία Susan McKenney για τις οδηγίες που έχει αφήσει ως πολύτιμη παρακαταθήκη σε όσους διδακτορικούς φοιτητές επιθυμούν να ακολουθήσουν την έρευνα που είναι βασισμένη στη σχεδίαση.

Ξέρω ότι ακούγεται κοινότυπο και συνηθισμένο αλλά δε θα μπορούσα να μην ευχαριστήσω την οικογένειά μου (τους γονείς μου, τους παππούδες μου, τις αδερφές μου και τα ανηψάκια μου) για την κατανόηση και την υπομονή που μου έδειξαν και την ηθική υποστήριξη που μου παρείχαν καθόλη τη διάρκεια της διατριβής. Τους ευχαριστώ ολόψυχα.

Τέλος θα ήθελα να ευχαριστήσω τους φίλους Αγγελική Κοκκινάκη, Μαριάννα Προδρόμου, Έλενα Ιάπωνα, Ελίνα Χριστοφόρου, Γιώργο Δελληγιανάκη και Βίκη Παπαδοπούλου για την έμπρακτη συμπαράσταση και την υπομονή που έδειξαν κατά τη διάρκεια των διδακτορικών μου σπουδών. Κοιτώντας πίσω αναγνωρίζω την επίδρασή τους σε επίπεδο καλλιέργειας στάσεων

μέσα στην Ακαδημαϊκή ζωή. Ίσως να ξεχνώ κάποιον ή κάποια. Το σίγουρο πάντως είναι πώς δεν ήταν μια μοναχική πορεία.

«Οπότε αναρωτιέται κανείς: Για τι παλεύουμε νύχτα μέρα κλεισμένοι στα εργαστήριά μας; Παλεύουμε για ένα τίποτα, που ωστόσο είναι το παν.» (Ελύτης, 1979)

«Δε θέλω τίποτε άλλο παρά να μιλήσω απλά, να μου δοθεί ετούτη η χάρη» (Σεφέρης, 1942)

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**List of abbreviations**

4C/ID Four Components Instructional Design

AI Artificial Intelligence

AHS Adaptive Hypemedia System

ATI Aptitude Treatment Interaction

CSCD Computer Supported Collaborative Design

CSCL Computer Supported Collaborative Learning

DBR Design-Based Research

ITS Intelligent Tutoring System

GT Grounded Theory

LD Learning Design

PCK Pedagogical Content Knowledge

RCT Randomized Controlled Trials

RE Requirements Engineering

STEM Science, Technology, Engineering, Mathematics

TEL Technology Enhanced Learning

UoL Unit of Learning

VARK Visual, Auditory, Read/Write, Kinesthetic

# Chapter 1. The Research topic

## 1.1 Statement of the problem

The cornerstone assumption of this thesis is that teachers are the primary change agents of an educational system (Cobb, 2001; Villegas & Lucas, 2002; Mor, 2013). Their work is to make sound educational decisions in order to facilitate the growth and development of their students (Villegas & Lucas, 2002). Another assumption is that teachers adapt their lessons with or without the use of technology, using their wisdom of practice (Shulman, 1986). The problem is that, although the benefits of adaptive eLearning have long been discussed, the engagement of teachers at a large scale with adaptive elearning designs still remains a challenge.

In the field of Technology Enhanced Learning[1] (TEL), the initial conceptualisation of an ICT-infused learning design, its development using technological means and its enactment with learners, plays a central role (Muñoz-Cristóbal, 2012). Designing activities in the context of TEL entails making decisions about strategy, interactions, interfaces, content and its delivery (Sims, 2006). Also, it includes tasks such as (Kenny et al, 2005) writing learning objectives, identifying the types of learning outcomes, selecting media formats, delivery modes etc. Although designing activities in the context of TEL is a demanding task, there is a growing body of research that verifies the role of teachers as designers in this context. In addition, it has been suggested that their active involvement in the Learning Design process might have a positive impact on their professional development and in turn, on student learning (Kali & McKenney, 2012). Yet, the concept of teachers as designers for adaptive e-learning still remains underexplored while the benefits of adaptive e-learning for the students have been frequently mentioned. My thesis extends the notion of "teachers as designers" (Carlgren, 1999; Angeli & Valanides, 2005; Cross et al. 2008; Fuhrmann, Kali, & Hoadley 2008; Laurillard 2008; Voogt et al. 2011) to "teachers as designers of adaptive e-learning" by exemplifying paradigms of teacher-led design for adaptive e-learning.

[1] In the context of this thesis, the terms eLearning and Technology Enhanced Learning are used interchangeably and are defined as "the use of information and communication technologies (ICTs) to facilitate and enhance learning and teaching"(Kopper, 2007, p. 356).

My thesis makes the following claim: on the basis that teachers adapt their lesson with or without the technology, adaptive e-learning is a field where teachers can serve as designers of activities, lessons, courses etc. Yet, the design of a user-friendly and standards-based digital environment that teachers could easily be used to create adaptive e-learning components still remains an open research issue and, as already mentioned, the role of teachers as designers of adaptive e-learning also remains underexplored in the bibliography. The main questions examined in my thesis are the following:

- how can teachers serve as designers for adaptive e-learning?
- how can the affordances of adaptive e-learning help students overcome the inherent difficulties of the subject matter? Also, for which students the adaptive e-courses that are focusing on the inherent difficulties of the subject matter are more beneficial?
- what are the design requirements of a user-centered digital environment for adaptive e-learning?

More specifically, the first question is related to a) the design of adaptive e-courses that focus on the inherent difficulties of the subject matter and b) the design of a user-friendly technological platform for adaptive e-learning. The third question deals with two sub-problems: 1) how can we design a learning environment for adaptive e- learning in a user-centered way? and 2) how can we prioritise the design requirements of a digital environment in a user-centered way?

This thesis discusses how can the affordances of adaptive e-learning can help students overcoming the inherent difficulties of the content to be taught, while a) proposing robust and valid mappings between learner characteristics and appropriate content/media and b) utilizing remediation techniques that cater for these difficulties. The inherent difficulties of the content are well-known to the research and educational community and apply universally. An example coming from the mathematics education is the “freshman’s dream” error[2]. An experienced mathematics teachers knows that high- school students would think that $(a + b)^2 = a^2 + b^2$ and freshmen would think that $(a + b)^n = a^n + b^n$. In order to be in a position to design adaptive e-

[2] http://en.wikipedia.org/wiki/Freshman%27s_dream

courses massively the teachers needs to have in their minds helpful methodologies and have access to appropriate tools, which are compliant with these methodologies. This is exemplified in the scenario below:

Panagiota is a mathematics teacher with several years of teaching experience. She tries to adapt her lesson taking into account her students' profiles and she frequently integrates technology in her lessons. She doesn't have substantial technical knowledge but she is computer literate. She decides to engange herself in the creation of adaptive eLearning courses in order to cope with the different learning needs of her students more effectively. The adaptive e-course will mimic her in-class behavior in conjunction with the provision of differentiated instruction and will be based on sound theoretical frameworks that are derived from teachers' practice.

Panagiota will create an adaptive e-course about identities. The creation of an adaptive e-course begins with the inherent difficulties of the subject matter. Panagiota knows from her experience that, in the ratio and analogies course, students are facing difficulties: they crete pseudo-analogies in their minds and they use the additive reasining (instead of the multiplicative reasoning). Once the creation of the adaptive eLearning course and its validation in real classroom settings will be finished, Panagiota will upload the e-course (packaged in a .zip file) at the school server to give the opportunity to other teachers to engange with it. The inherent difficulties of the subject matter apply universally, thus there is no need to re-purpose the adaptive e-courses which are based on these difficulties. Panagiota had already used one adaptive e-course before which was originally created by another mathematics teacher in one of her lesson and the results were quite satisfactory.

Panagiota begins the design process by writing: the title/topic of adaptive e-course (ratios and analogies), the associated concepts (ratios, analogies), the inherent difficulties of the subject matter (pseudoanalogies, additive reasoning) and the prior knowledge (multiplication, division) required on behalf of the students. Next she thinks about the adaptation strategy, that is, which adaptation methods and which adaptation parameters will be exploited and how will they be combined? Following, she designs the course diagram and the alternative learning trajectories using a simplified version of the UML. This process enables visualized adaptive eLearning design. Next, she populates the e-course with suitable learning resources or learning activities. She knows that having extra learning activities at the end of the e-course will prevent classroom management problems, since not all students are expected to end the e-course simultaneously. The reason is that the adaptive e-course she designed takes remedial actions in case the student cannot cope with the mathematics problems at stake and provides additional learning activities to those students that are facing difficulties.

## 1.2 Purpose and motivation

It is generally accepted that "one-size-does-not-fit-all" and that the students' performance can be improved through adaptive e-learning environments that suit their needs (Lee & Park, 2007; Kim, 2012; Hwang et al., 2012). The main advantage of adaptive e-learning compared to the traditional direct instruction that takes place in the classroom is that, especially in classes of large audiences, instructors can't deviate from the syllabus to meet the diverse needs of their students. These diverse needs stem from the fact that they have diverse (mental and physical) characteristics and it has been proved empirically that individual differences have serious implications in learning (Ford and Chen, 2000; Magoulas, Papanikolaou & Grigoriadou, 2003). Consequenlty, adaptation to these differences in a learning educational environment is a necessity (Nguyen & Do, 2008).

Effective adaptive e-learning can contribute to (Peter, Bacon &Dastbaz, 2010): a) increased student satisfaction, b) reduced time taken to learn and c) improved learner's retention. The manifestation of effective adaptive e-learning in the context of my thesis takes the form of e-courses that implement an effective adaptive learning strategy. In general, central to an adaptive learning strategy are: the domain model that contains the knowledge about the domain and the curriculum structure (Yasir & Sami, 2011) and the learner model that contains information about an individual learner (ibid). The thesis proposes a domain theory on adaptive e-learning that incorporates a domain model which is heavily affected by the teachers Pedagogical Content Knowledge combined with a learner model which a) exploits a learning style typology in line with teachers' practice (Mavroudi & Hadzilacos, 2014), b) is based on a robust methodology of mapping the learner style preferences with the types of learning activities the learner engages with (Mavroudi & Hadzilacos, 2012). According to Shute & Towle (2003), a methodology that produces robust and valid mappings between learner characteristics and appropriate content constitutes an indispensable ingredient of any adaptive learning milieu that provides engaging learning experiences.

The widespread adoption of adaptive e-learning and remediation technologies in included among the challenges of the 21st century by the European Commission which argues that adaptive e-learning needs to open up and become part of the mainstream education of the 21st century. But, it is my understanding that this has to be done in ways that are close to teachers' everyday practice and accumulated knowledge. My thesis is in line this vision of opening up education and teachers' involvement in the vision of mainstreaming adaptive e-learning in a large scale. The European Commission has provided general directions: "a technology platform to provide a framework and roadmap for stakeholders […] to develop innovative technologies for learning (adaptive solutions, learning analytics, augmented reality, mobile learning, etc.), address standards for interactive content (covering its composition, re-use and distribution) and its adaptations into learning scenarios."[3]

Concerning the issue of addressing standards, the study is motivated by the fact that an opportunity is being shadowed by a problem: adaptive e-learning can be managed by the IMS-Learning Design specification (the opportunity) which has been criticized as being too technical (the problem). Indeed, the specification has been frequently used for adaptive, web-based learning (Burgos et al., 2007; Gómez, Mejía, Huerva & Fabregat, 2009; Magnisalis & Demetriadis, 2012), but it has been criticized for being too cumbersome for non-technical users (Gómez et al., 2009) and my research confirms it. This restricts the development of IMS-LD compliant courseware to these sub-groups of stakeholders (researchers, teachers, instructional designers) that have a fairly good technical background and who are willing to spend time and effort dealing with technical rather than pedagogical issues. An initial interesting challenge (which is documented as part of my preliminary research) of this study was to disprove this, i.e. to create components of adaptive courseware which are IMS-LD compliant and do not require much technical knowledge and furthermore, to design, develop and evaluate the courseware. For

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[3] Horizon 2020 Program, Topic: ICT 2015 - Information and Communications Technologies
http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/9086-ict-20-2015.html

some researchers, the motivation for seeking standardization in adaptive e-Learning is directly linked to the minimisation of cost factors that relate to the low level of reuse due to proprietary models and representations of system knowledge, adaptation logic, etc. (Conlan et al., 2002a; Paramythis &Loidl-Reisinger, 2003). The only one of the open eLearning standards that currently supports the explicit representation of dynamic behaviour on behalf of the system is the IMS Learning Design specification (Paramythis &Loidl-Reisinger, 2003).

**Challenges: Why is it difficult?**

Fifteen years ago Federico stated that ‘‘theoretical or conceptual problems, in addition to methodological difficulties, have limited the practical payoff from research in adaptive instruction” (Federico, 1999, p. 662). More recently, Park and Lee (2007) also expressed their concern about the lack of scientific evidence in the research on characteristics and background variables that have to be considered in adaptive instruction. They continued on by asserting that, in this way, it is difficult to provide guidelines for creating adaptive e-learning environments. In addition, challenges with regards to the selection of the adaptation parameters, the adaptive learning strategy and the adaptation methods abound in the recent bibliography. Shute and Towle (2003) expressed their worries on misapplying the concept of adaptive eLearning. They argued that adaptive learning is not just concerned with "adapting the content or instruction to meet the constraints of the learning device, or adapting the interface to meet the needs of learners with different abilities and characteristics" (p. 113). Moreover, it is mentioned that "many researchers are involved in defining adaptivity as an adjustment of content or interface, based on assessments of learning styles or cognitive styles, only few are concerned about adaptivity as integral part of instructional design and therefore testing the effectiveness of the instructional design" (Shute & Towle, 2003, p. 113). Other major research issues in the field are: the development of more user-friendly and integrated authoring and runtime tools (Hernández-Leo et al., 2006), authoring of adaptive learning designs (Van Rosmalen et al., 2006), the graphical representation of learning designs (Paquette & Marino, 2006), the integration of assessment in learning designs (Joosten-ten Brinke et al., 2005; Pacurar et al., 2004), and the use of Semantic Web tools with learning design (Amorim et al., 2006; Knight et al., 2006).

## 1.3 Contribution

Since Rich (1983) claimed that a much better system, compared to the one that targets to the "typical" user, would be one in which the interface would be tailored to user needs, much progress has been made in conjunction with adaptation and personalisation. Increasingly, researchers started to understand that one size does not fit all (Brusilovski, Kobsa & Nejdl, 2007). Vandewaetere et al. (2011) mention that there is a growing body of research demonstrating that adaptive learning "is superior to the uniform approach of more traditional and one-size-fits-all teaching approaches" (p. 119). Nowadays, it is generally accepted that the students' performance can be improved through adaptive e-learning environments that suit their needs (Lee & Park, 2007; Kim, 2012; Hwang et al., 2012), since recent advances in information and communication technology (ICT) allow for the delivery of individually customized information and instruction to mass audiences simultaneously. A decade ago, mass individualization in education and in training communities was the "next big thing" (De Bra et al., 2004). Still, it is important to know under what circumstances and for which student groups adaptive e-learning is effective and provide empirical evidence to support educators' decisions when they design for adaptive learning purposes (van Seters et al., 2011).

With respect to the impact or the degree of adoption of adaptive elearning in the educational community worldwide, it was difficult for me to obtain a holistic view of what actually happens in the classrooms throughout the world. Some reports were identified that provide information about the adoption or the impact of adaptive e-learning at a country level. For example, a recent report coming from the Center for Digital Education (Izumi, Fathers & Clemens, 2013) in Canada mentions that "better quantitative, empirical research needs to be completed regarding the actual benefits of adaptive technology and the keys to success with respect to implementing and using it" ( p.24).

The added value of educational technology comes not from replicating things that can be done without the use of technology, but from using it to do things that couldn't be done otherwise. The true power of e-learning comes from the exploitation of the affordances of technology in ways that signify its added value (Shute & Towle, 2003; Angeli & Valanides, 2005) and one of the most obvious is about assessments and learning materials that adapt to students' needs (Shute & Towle, 2003).

**Who could benefit?**

The proposed methodology presented in Chapter 5 could be used by schools and universities that wish to exploit the affordances of adaptive e-learning in a way that capitalizes on the knowledge base of their tutors and their researchers. Also, the adaptive e-courses that I created during this study are licensed under creative commons license and are provided on request to anyone that wishes to inspect, edit, reuse or use them. The proposed adaptive e-learning strategy mentioned in Chapter 6 could be utilized by anyone who is interested in creating adaptive e-courses focusing on the inherent difficulties of the content. Since the learning goals here depend on these difficulties and these difficulties are not related to any national standards but apply across educational systems and countries the proposed strategy could have a broader impact compared to a strategy that would serve for example, learning goals related to any national education standards. In that sense, the proposed strategy caters for non-local, re-usable adaptive e-courses. Furthermore, the proposed design requirements along with the ensuing User Interface mockups of Chapter 7 could be exploited by eLearning vendors that seek to enhance their current adaptive e-learning systems or wish to design new ones. Additionally, the methodology behind the prioritisation of the design requirements mentioned in Chapter 7 could be useful to anyone that is interested in creating cost-effective software products that meet the end users' expectations. Finally, practitioners and researchers from other design disciplines than the instructional design could be influenced by the findings of Chapter 7 to reflect on their practices, like Computer Supported Collaborative Design. This is significant since there is a research trend lately that gradually gains ground which promotes the intercourse between the various design disciplines (Mor & Craft, 2012; Mor, Craft & Hernández-Leo, 2013).

Connection with the European policy**:** Through the programmes Erasmus+ and Horizon 2020[4], the Commission seeks to:

[4] For example, in the strand "ICT 20 – 2015: Technologies for better human learning and teaching" of the Horizon 2020 Framework Programme of the European Commission.

- reinforce the European leadership in adaptive elearning technologies for the personalisation of learning experiences
- promote research and innovation on adaptive elearning technologies & learning analytics
- speed up the rate of adoption on technologies for the modernization of education and training

Connection with the market and the industry worldwide**:** The Learning Impact Report, launched every year by the IMS Global Learning Consortium, aims to identify projects and trends in the use of technology to improve access, affordability and quality of education worldwide. Succinctly, the report of the year 2013 mentions that the market on adaptive e-learning products "continues to grow rapidly and diversify". Indeed, nowadays a number of commercial adaptive e-learning platforms exist. They are described in Chapter 2.

## 1.4 Organisation

In the context of this thesis the concept of "teachers as designers of adaptive e-learning" is viewed from two main perspectives: the development of practical skills (teacher capacity development), as well as, the development of theoretical understandings on designing ICT-infused scenarios and activities for adaptive e-learning purposes. For the development of practical skills, tools that meet the educators' expectations are needed. Towards this direction, my research proposes 1) a set of design principles, 2) use cases describing functional and non-functional requirements and 3) a set of User Interface mockups for a digital environment of adaptive elearning which meets the educators' expectations. More specifically, the proposal about this environment enables the authoring of adaptive e-courses and their enactment in the classroom.

In regards to theoretical understandings on how to design for adaptive elearning, a methodology is described which touches upon two theoretical frameworks derived from curriculum studies and didactics of Mathematics, respectively. These frameworks were useful in guiding the process of creating and evaluating adaptive e-courses. Also, they facilitated the collaboration and the discussions between me and the teachers that were the co-designers of the adaptive e-courses. The proposed methodology provides a roadmap through the design process, by mapping the design stages with the phases of the theoretical frameworks.

Finally, a domain theory on STEM (Science, Technology, Engineering, Mathematics) is suggested. It emphasizes an adaptive elearning strategy incorporated in the e-courses. This strategy and the ensuing e-courses were created and tested through a series of interventions in real classrooms settings. That is, the suggested methodology is more process-oriented, while the domain theory is more outcome-oriented. The figure below depicts the relationship of the teacher-led design endeavor with each of its constituent components, as well as the interplay among them (Edelson, 2002):

- The design methodology, which is prescriptive in nature and focuses on the design process adopted in the interventions; the emphasis is on the conceptual mappings between the steps of the Design-Based Research with the phases of the theoretical frameworks used.

- The domain theory, which is descriptive and based on the outcomes of the designed interventions; the emphasis is on the adaptive e-learning strategy which was incorporated in the e-courses.

- The design framework that prescribes a set of design principles and requirements behind an envisioned digital environment for adaptive eLearning.

The methodology and the domain theory are closely related since they were both adopted and refined respectively, in the same Design-Based Research process. Firstly, in a pilot study, an adaptive e-learning course was co-designed along with an educator and tested with a small number of students. In the next consecutive cycle, five e-courses were created and tested in real classroom settings with many students and five educators that were co-designers. All the adaptive e-courses incorporate in their design the same adaptive eLearning strategy.

The relationship between the design framework and the domain theory is related to conjectures. This relationship is explicitly mentioned in Sandoval (2004): "designed learning environments embody design conjectures about how to support learning in a specific context, that are themselves based on theoretical conjectures of how learning occurs in particular domains" (p.5). In the case of this thesis, embodied conjectures were used throughout the design of the adaptive learning environment. An embodied conjecture is “a conjecture about how theoretical propositions might be reified within designed environments to support learning” (p.6). An example of a conjecture: the outcomes of the domain theory confirmed that adaptation using two methods (differentiation of learning activities, differentiation of content presentation) is more efficient than using one method (different learning activities). This was mirrored in the design of the digital learning environment discussed in Chapter 7 in the form of a design requirement for the easy authorship of “rich” adaptive learning designs (i.e more than one method could be integrated in the design in a user-friendly way and could be combined meaningfully with more than one adaptation parameters). Another example of a conjecture: the outcomes of the interventions confirmed that the VARK (Visual-Aural-Read/Write-Kinesthetic) typology is preferable among other learning styles typologies. Consequently, the designed environment discussed in Chapter 7 incorporates this specific typology in order to author an adaptive e-course that exploits learning style, as an adaptation parameter.

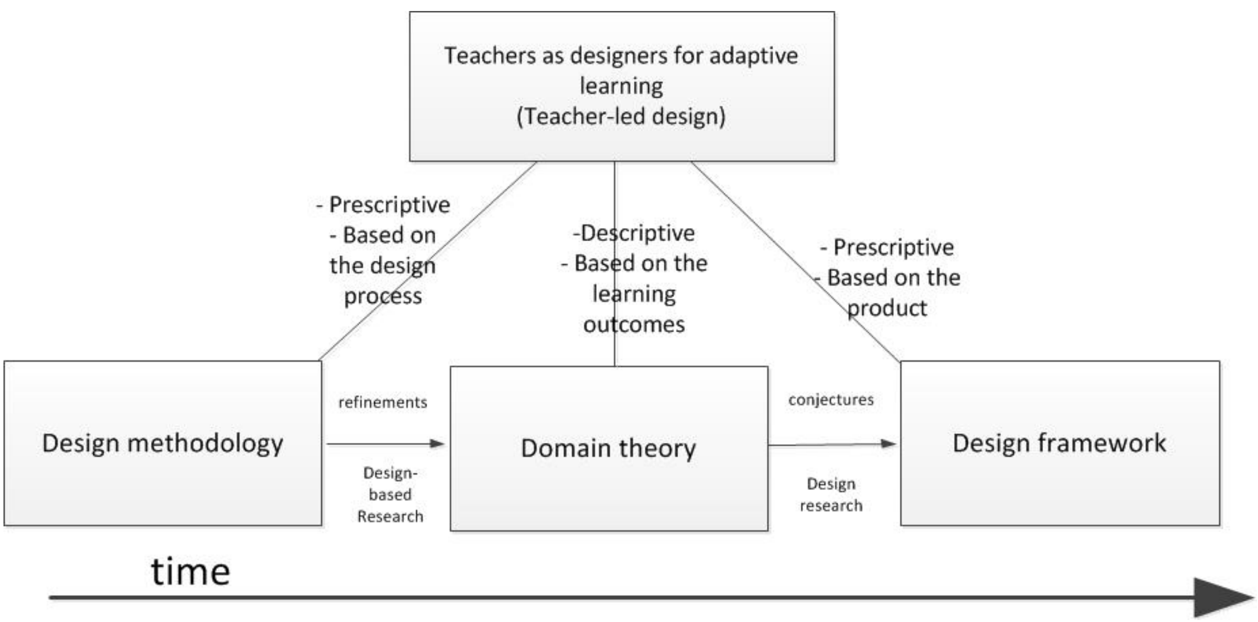


**Figure 1The research roadmap**

This sub-section attempts to present a high-level synthesized conceptual framework with a unifying view of the methodologies adopted during all intervention phases. To this end, mappings of how the methods are linked to the research questions are discussed below, as well as, pointers to the actual sections within individual thesis chapters, where methodologies are currently described in detail. Concerning the first research question (how can teachers serve as designers for adaptive e-learning?), I used mixed (qualitative and quantitative) methods and tools closely related to the ideas of Pedagogical Content Knowledge that helped me discern which results concern the context of the study and which of these concern the focus of the study, that is, to better understand teachers as designers for adaptive e-Learning. In particular, I exploited Design-Based Research as an umbrella method in the first two phases of my research, in which the teachers served as co-designers of adaptive e-courses. Coupled with DBR, a discussion protocol was used to guide the discussion and the collaboration between me and the teachers. The discussion protocol was based on the two theoretical frameworks presented in detail in Chapter 3. The third research phase, involves a design research study in which teachers served as co-designers as well as requirements validators of a user-friendly digital environment for adaptive eLearning. This phase cannot be considered as DBR, because DBR is design research for education and, as such, it is conducted in naturalistic settings where learning happens (i.e. classrooms, lecture halls, labs, museums etc). In this phase, a scenario-based elicitation requirements approach (explained in Chapter 7) was exploited in tandem with the Grounded Theory methodology (explained in detail in Chapter 3) to analyse the ensuing scenarios.

Concerning the second research question (how can the affordances of adaptive e-learning help students overcome the inherent difficulties of the subject matter and for which students the adaptive e-courses that are focusing on the inherent difficulties of the subject matter are more beneficial?) an observation protocol in tandem with screen recording and video analysis was used. The aim was to record the interactions between the teacher and the students as well as the interactions among the students while working with the pilot adaptive e-course. The goal was the refinement of the adaptive elearning strategy that was later on incorporated in all the adaptive e-courses which were created for the scope of this study. In this second phase of this study (which corresponds to the third phase of the DBR method) a randomized controlled trial, with a pre-test–post-test control group design was conducted.

Finally, concerning the third research question (what are the design requirements of a user-centered digital environment for adaptive e-learning?), it was answered through the use of an iterative requirements engineering approach (Chapter 7) consisting of requirements elicitation (using the scenario-based elicitation approach mentioned above), specification (using the Grounded Theory as a starting point) and validation (using online questionnaires, and dedicated collaboration protocols, one for adult participants and one for children). To prioritise the ensuing design requirements, the use of Qualitative Comparative Analysis was exploited. The latter method is described in detail in Chapter 3.

## 1.5 Summary

In this section, an overview of the topics and their structure, as well as, the research activities that were undertaken over the duration of this PhD research study are described briefly.

Chapter 2 ("Background") discusses related work on the topic. Firstly, various central concepts in the domain of adaptive learning are defined. In particular, the concepts of: adaptation, adaptive learning and adaptive learning systems. Moreover, some concepts, like

- the triplet: adaptation, personalization and context-awareness
- the triplet: adaptation, adaptivity and adaptability.

are better framed through a compare and contrast process, which is attempted in this thesis.

Following, the IMS-Learning Design specification is described as the only specification currently in the educational technology field that can serve as a means of implementing adaptive Units of Learning. This is true since this specification has three levels of implementation (levels A, B and C) and those systems that are compliant with level B (or level C, there is an inheritance rule among the levels) are adaptive. In addition, the affordances of adaptive elearning and the constraints of adaptive elearning systems are discussed. These systems support the creation of adaptive Units of Learning i.e. Units of Learning which incorporate a strategy for adaptive elearning. In turn, a strategy for adaptive elearning is the incarnation of rules between adaptive learning methods and adaptive learning parameters. Examples of various adaptive elearning systems are presented along with a short description of the adaptive elearning strategy (or strategies) they implement, focusing on those strategies and systems that incorporate learning or cognitive style and student knowledge as adaptation parameters in their student (or user model)

model. Prior to that, a review of the most prominent models of learning or cognitive styles used in research on adaptive elearning is presented. The chapter concludes on difficulty levels in the implementation of an adaptive elearning strategy.

The introduction of some new technology in the process of education does not by itself constitute a new type of learning. However, it may constitute an opportunity for new ways of learning. To exploit this opportunity, design methodologies are needed and this thesis proposes design research and Design-Based Research as a suitable methodological approaches. They both relate to iterative design and formative research in complex real world settings. Also, in these methods the design researchers begin with hypotheses and principles in mind, which use to guide the design process but, interestingly, they are not specific or detailed enough to determine every design decision (Edelson, 2002). Another interesting point that characterizes all kinds of design research is that it exploits the design process as an opportunity for learning on behalf of the researcher through formative and iterative reflection on the outcomes. Both prescriptive and descriptive lessons can be learnt in design research, as opposed to the traditional empirical research in which the findings are descriptive (Edelson, 2002).

In addition, two other methodological tools were used: a) the Grounded Theory, a qualitative research methodology that allows key themes to be emerged mostly from textual data through iterative coding and b) the Qualitative Comparative Analysis, a method that can reveal causality among the problem variables. Chapter 3 continues with the discussion about the theoretical frameworks exploited in this thesis: Shulman's model of Pedagogical Reasoning and Action (a generic model derived from curriculum studies) and Simon's Mathematical Teaching Cycle (a domain-specific learning design theory in mathematics). Although these models were originally created in an digital era distinctively different from today's, they employ cognitive constructs such as: transformation of the content into knowledge through adaptation and tailoring to student characteristics (the former) and the concept of the student's hypothetical learning trajectory (the latter) that pertain to the principle of differentiated instruction. Thus, they have served as the basis of the proposed design methodology described in Chapter 5 of the thesis.

Chapter 4, titled “Preliminary research and design” is related to the issue of using e-learning standards for adaptive learning and Learning Design, focusing on the exploitation of IMS-Learning Design and how it can serve both. I designed and created various educational components, as examples of its potentials for adaptive learning. An adaptive e-course, adaptive educational components (such as an educational recommender system and adaptive pathways/rules) were created and demonstrated to novice instructional designers since they were interested in creating their own adaptive learning designs. These components were later evaluated by the small group of novice instructional designers, in order to confirm what the recent literature states: that the implementation logic is difficult for novice instructional designers and educators. Succinctly, the hypothesis was confirmed since the relationship between their perceived value and their usefulness was rated as mediocre, even when programming knowledge was not required to create the components.

From the tools perspective, there is a lack of teacher-friendly authoring tools for adaptive UOLs and “it is clear that new tools and representations are needed if teachers are to intervene in editing and creating UOLs” (Griffiths and Blat, 2005, p. 2). And since teachers adapt their lessons with or without the use of technology, two other preliminary surveys were conducted in order to capitalize on the teachers’ practical wisdom:

- a survey on the adaptation parameters that teachers and instructional designers are using to adapt their lessons (with or without the use of technology)
- a survey on the learning style typology that teachers find close to their daily teaching practice

The chapter continues on by proposing mappings between different types of learning activities and learning style preferences based on the typology suggested in the VARK (Visual, Aural, Read/write, Kinesthetic) model. The preliminary research on the preferred learning styles typology revealed that the VARK model is the one that teachers can associate better with their practices. The chapter concludes with the usefulness of Computer Supported Collaborative Design in the process of creating adaptive learning designs. This conclusion is derived from a case study where twelve graduate students undertook the demanding role of the adaptive e-course developer and worked collaboratively on an authentic and complex design task in the context of open and distance tertiary education. The students had to work in groups in order to conceptualise and design a learning scenario for adaptive learning, develop learning materials and adaptive learning strategies, implement the respective adaptive e-course and finally, reflect on their experience. As mentioned, implications of this study include design guidelines towards an environment that implements complex adaptive behaviour in today's learner-generated digital world where Computer Supported Collaborative Learning (CSCL) often converges with Computer Supported Collaborative Design (CSCD). As a result, the design framework depicted in figure 1 enraptures CSCD features.

Chapter 5 describes the proposed design methodology and discusses its contribution as a means of integrating theory, ICT tooling and the practical wisdom of teacher. This chapter proposes a methodology of designing and developing adaptive learning e-courses that focuses on how the teacher's Pedagogical Content Knowledge (PCK) has intervened, informed and affected the design choices. The methodology proposed was applied during a pilot study through an adaptive e-course in mathematics, specifically in the domain of analogies and ratios. The application of the methodology proposed in the context of this specific intervention involved: a) active collaboration of with a mathematics educator in order to design the adaptive e-course, b) development and implementation of the e-course, c) reflection and refinements concerning the design of the adaptive e-course. The final products of the intervention were: an adaptive learning strategy and an adaptive e-course in the domain of mathematics. Also, a roadmap is proposed concerning the stakeholders' involvement, especially the active role of the teacher in the design process. It is based on conceptual mappings between the design-based research steps and the theories used to orientate the research.

In the domain of Technology Enhanced Learning a system needs to know what a student knows, doesn't know or knows incorrectly and a problem that often occurs is that a student "does not always know what he doesn't know, much less what he knows incorrectly" (Rich, 1983). Adaptive elearning systems try to answer that problem by implementing an adaptive elearning strategy. Chapter 6 discusses the proposed design theory on adaptive elearning and the adaptive elearning strategy is presented. Chapter 6 generalises on Chapter 5, since the latter discusses how the adaptive e-learning strategy was formed during a pilot study that took place in two iterative cycles of design and refinement, while Chapter 6 discusses what happened in the third iterative cycle. Reports on the empirical findings of five interventions that were undertaken to investigate the impact of the proposed adaptive eLearning strategy. Also, the profile of the students that followed the adaptive e-courses is interrogated aiming to investigate possible correalations between students' prior knowledge on the learning topic, their age and their motivation on the respective domain with their performance gains. Quantitative results coming from measurements related to students are triangulated with qualitative data derived from semi-structured interviews with the participant teachers, and also associated with previous research work. Finally, a sub-chapter is dedicated to the intricacies of the technical work that I had to undertake for the creation of the adaptive e-courses and the configuration of the online player from which the e-courses were accessed.

Chapter 7 paper discusses a requirements engineering process that exemplifies teacher-led design in the case of an adaptive elearning system. Such a design milieu poses various challenges and still remains an open research issue in the field of adaptive learning. Starting from a scenario-based elicitation method, the whole process was agile and participatory, profoundly affected by twenty novice instructional designers and eight children. Requirements validation took place in iterative cycles which refined the design of the envisioned targeted system. The results are confirmed both by simple statistical measures as well as through the use of Qualitative Comparative Analysis, a method that showcases causality between the research variables. The contribution of the chapter is twofold: a) it exposes the design of an environment that addresses the related challenges and b) it provides a way of framing key requirements into a set of critical success factors for meeting the end users' expectations. The latter could be crucial in cases where the available resources are limited, but the quality of the product must not be sacrificed. Consequently, the proposed methodology enhances the requirements prioritisation process in a user-centred way.

The first section of Chapter 8 summarises the findings of the research by revisiting the research questions and justifying the contribution of each chapter in answering those questions. The second section of the chapter discusses the implications of the research, whereas the third section discusses the limitations of  the research and “lessons learnt”. Finally, the chapter concludes with reccomendations for future research.

# Chapter 2. Background and focus

## 2.1 Adaptive learning and adaptive instruction

Adaptive e-learning is generally perceived in the context of computer-based learning environments that can interact with a student to provide the most suitable instruction. This perception suggests an instruction point of view and implies that "it is not students' learning that adapts, but the instruction provided by the system" (van Seters et al, 2012, p. 943). Similarly, adaptive instruction that which varies according to the needs of the individual student in developing knowledge and skills required for a learning task (Corno and Snow, 1986). Whether it is delivered by educators or by computers, any form of instruction can be adaptive, if it varies depending on the different student learning needs and abilities (Lee & Park, 2008). One simple case of adaptive instruction is varying the pace of instruction.

More broadly speaking, the meaning of the term "adaptive learning" depends on the context of its use since the term has been frequently devised by various communities (biology, organizational learning, cybernetics, e-Learning, pedagogy, climatology, evolutionary research). For example, from the perspective of learning in organisations it has been defined as "the investigation and subsequent changes in behaviors, technologies, or beliefs undertaken in response to negative feedback" (Tyre & Von Hippel, 1997). In another context, adaptive learning refers to "the capacity to be able to cope with changes in the environment, whether internal or external in origin. Without this capacity, living beings cannot mature, grow, or survive" (Voci & Young, 2001). These definitions refer to adaptation as the result of learning and they are not related to adaptive instruction as the first definition in this section does .

However, adaptation in e-learning systems is about "making adjustments in an educational environment in order to accommodate individual differences" (Magoulas et al, 2003, p. 3). Consequently, adaptation in e-learning can be described as "a method to create a learning experience for the student, but also for the tutor, based on the configuration of a set of elements in a specific period aiming to increase the performance of pre-defined criteria" (Van Rosmalen et al., 2006; Burgos et al. 2007, p. 162). A technology-centered definition argues that adaptive e-learning is the usage of technology which helps the students in their learning process by providing content and services to meet the needs of individuals or groups (Kara & Sevim, 2013). Paramythis and Loidl-Reisinger (2003) consider an e-learning environment adaptive if it monitors the user activity and interpret it on the basis of domain-specific models, infers user requirements and preferences out of the interpretation and, acts upon the user knowledge and the subject matter in order to dynamically facilitate the learning process. Constituent characteristics of the dynamic adaptive e-learning process are diversity and interactivity (Wang, Wang & Huang, 2008; Beldagli & Adiguzel, 2010). The diversity is addressed through differentiated content and the interactivity is addressed through differentiated services.

For the scope of this thesis adaptive e-learning is an umbrella term that describes the techniques used by computer-based learning environments that attempt to mimic what a teacher would do in a learning situation provided that each student has different learning needs.

## 2.2 Clarification of relevant terms

The appreciation of fuzziness and the subsequent clarification of the following terms is necessary since interpretations for these terms used in literature abound (Froschl, 2005).

Adaptivity and adaptability**:** Adaptivity and adaptability are frequently used terms in the literature (Akbulut & Cardak, 2012) and numerous definitions of adaptive and adaptable systems exist (Boticatio & Santos, 2007). Oftentimes the definitions found in the literature are used mistakenly to express the same thing (Barrios, Mödritscher & Gütl, 2005) and other times they are conflicting. For example, in Paramythis and Loidl-Reisinger (2003), the term "adaptation" is used as a synonym for "adaptivity", whereas in Dagger et al. (2004), the term "personalisation" is used as a synonym for "adaptability". On the other hand, several authors (Kay, 2001; Magoulas et al, 2003) have pointed out the difference between the two main different forms of adaptation, "adaptivity" and "adaptability". Depending on who has the control of or who takes the initiative to the adaptation, the learner or the system (Kay, 2001), an e-learning system is adaptive or adaptable or both. Adaptivity refers to the processes where the system adapts "using some data or knowledge about the learner in a system controlled way" (Magoulas et al., 2003, p. 4), whereas adaptability is enabled when "the system supports end-user modifiability providing student control" (ibid). In an adaptable system, the user is able to modify the system parameters to suit her needs. Consequently, adaptability is the option delegated to learners to customise the learning experience by themselves (Burgos, Tattersall, & Koper, 2007) specifying how the system will be altered. In an adaptive system the needs of the learner are assumed by the system itself and, thus, it adjust its behavior accordingly (Froschl, 2005). For example, adaptable web portals allow the users to select which information they want to see and how this information will be displayed.

In other words, program controlled adjustments are referred to as adaptivity while learner controlled ones are referred to as adaptability (Burgos, Tattersall, & Koper, 2007). For example, in Angeli et al. (2014) the authors discuss an adaptive e-learning system that combines adaptivity and adaptability while the control of the adaptation process is shared between the users and the system. Input by the user originates in the form of self-perceived ratings of their cognitive load (repeatedly asked every 15' minutes). Then, the system asks the student whether she wishes to undertake a less demanding task, in case of highly rated cognitive load or a more demanding task in the opposite case, or, alternatively, to stay in the current task.

<u>Adaptation and context-awareness:</u> context-awareness is another term that is frequently met in the recent bibliography along with the term adaptation, and the two terms are often treated as synonyms (Chaari, Laforest & Celentano, 2004). Frequently context is defined by example, since it is identified by the parameters that pertain to it (Schilit & Theimer, 1994; Ryan et al. 1997; Brown, 1996; Dey, 1998):

- Environmental data, such as the user's location and orientation, temperature, time of day, season, identities of nearby people and objects and changes to those objects and so forth
- User data, such as the user's identity (age, gender etc), emotional state, focus of attention, cognitive or learning style, performance and so forth
- Usage data, such as hardware, software, network bandwidth and so forth

Dey and Abowd (2000) claimed that defining context by example is problematic and attempted to provide a solution by defining context in a more abstract and prescriptive (as opposed to descriptive) way: "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" (p. 3-4).

Although tightly related, context-awareness and adaptation refer to different capabilities. Adaptation is the capability of providing different versions of a service or different presentations of a document, in order to suit the needs of the user, the characteristics of the environment, of the equipment, etc. (Chaari, Laforest & Celentano, 2004). Context-awareness is the capability of perceiving the many aspects of the user situation and, consequently adapting the system behavior, i.e., the services, the data and the user interface (ibid). Therefore, adaptation is the goal of context-awareness. For the scope of this thesis, this position is adopted.

Adaptation and personalisation: while research papers for adaptation and personalisation abound in the recent literature, often these terms are confused or used interchangeably or in a misleading way (Barrios, Mödritscher & Gütl, 2005). Barrios et al. (2005) mention that "personalising is the same as adapting towards a specific user, or in other words, personalisation systems represent a specific subtype of general adaptation systems" (p. 122). That is, personalisation is a special form of adaptation. With regards to personalisation, two viewpoints are outlined in (Gruber et al, 2010): 1) personalised learning as "individualized and tailored educational experiences" (p. 2) which embraces personal relevancy and students' involvement in the learning process and 2) personalised learning as "processes that support learners to take responsibility and control over their learning" (p. 2). In another paper, the definition of personalised e-learning is mostly aligned with the second option: "personalised eLearning employs an active learning strategy which empowers the learner to be in control of the context, pace and scope of their learning experience" (Dagger et al, 2004, p.2). An interesting distinction between personalised learning environments and adaptive learning environments is suggested in Vandewaetere et al. (2011) in conjunction with the types of characteristics that are incorporated in the design of such environments. The distinction pertains on the difference between learner characteristics and learning characteristics. The former are more closely connected to the research on adaptive learning, whereas learning (process) characteristics are more closely connected to the research field of personalised learning. The latter typically take into account external characteristics such as: mobility, place and time, etc. These characteristics are conceptually close to what it is defined as "context" in the previous section. For the scope of this thesis, context awareness is related to all three types of the parameters mentioned above (environmental, user, usage), whereas adaptation is related only to the user parameters.

### 2.3 Approaches of adaptive learning and instruction

The categorisation of adaptive learning systems presented in this section provides a historical overview (Mödritscher et al, 2004) and it is proposed by several researchers (for example, Lee & Park, 2007; Vandewaetere et al. 2011; Begdagli & Adiguzel, 2010). It distinguishes between:

- the macro-adaptive approach, which addresses adaptation by allowing different alternatives for the selection of learning objectives, curriculum content, and delivery systems, based on the student profile and characteristics. These characteristics are: cognitive or learning styles, student's learning goals, delivery systems, achievement levels, levels of detail etc (Mödritscher et al, 2004; Beldagli & Adiguzel, 2010).

  These characteristics affect the adaptive e-learning systems in different ways, such as: diagnosing the learner's specific learning needs and providing instructional prescriptions for them (Lee & Park, 2008), defining preconditions for learning content, adapting to the students' learning styles and achieving different types of learning objectives in accordance with the individual student needs or abilities (Mödritscher et al, 2004). Pre-planned adaptive e-learning strategies are then created by the experts for the various categories of learners (Goldberg et al, 2012).
- the Aptitude–Treatment Interaction (ATI) approach, which "suggests different types of instruction and/or different types of media for different students" (Belgagli & Adiguzel, 2010, p. 5757; Mödritscher et al, 2004, p. 2; Burgos et al, 2006) and it is based on the idea that if learner aptitudes are paired with the right treatments, prediction of learning outcomes would be more effective (Saba, 2002).

  Aptitude is defined as "any individual characteristic that increases or impairs the student's probability of success in a given treatment" (Park, 2003, p. 655) and treatment as "variations in the pace or style of instruction" (ibid). ATI research aims to "provide information about learner characteristics that can be used to select the best learning environment for a particular student to optimize learning outcome" (Shute & Towle, 2003, p. 106).

The aim of the ATI approach is to find linkages between learning and aptitudes (Mödritscher et al, 2004). To this end, one aspect of the ATI approach deals with the locus of control on the learning process e.g. it is more effective to limit the control for students with low-levels of prior knowledge (Mödritscher et al, 2004). Classes of aptitudes in the ATI research identified by several studies are (Park, 2003; Mödritscher et al, 2004): a) intellectual abilities consisting mostly from reasoning ability, visual spatial ability, verbal ability, mathematical ability, memory space, and mental speed, b) cognitive or learning styles, c) (prior) student knowledge, d) anxiety, achievement motivation, and interests and e) self-efficiency, which is "a student's evaluation of his or her own ability to perform a given task" (Park & Lee, 2003, p. 657). Also, metacognitive abilities are considered important in the ATI approach and researchers study their impact to variables such as, the feedback and the control (Beldagli & Adiguzel, 2010). Recently researchers recognized cognitive processing capacity as an influencing aptitude, thus new adaptive systems that incorporate implications of cognitive load theory into their design have been developed (Vandewaetere et al., 2011).

- the micro-adaptive approach, which diagnoses student's specific learning needs during instruction and consequently provides suitable instructional prescriptions and tactics for these needs (Mödritscher et al., 2004). That is, micro-adaptive instructional models rely mostly on on-task rather than pre-task measures. Intelligent Tutoring Systems (ITSs) are an example of this approach. In the case of macro-adaptive instruction, the differentiation of teaching operations is frequently used over larger segments of instruction (Park & Lee, 2003). On the contrary, a micro-adaptive model uses the temporal nature of learner abilities and characteristics, especially the dynamically changing ones, such as affective states, response errors, response latencies etc. Monitoring the user's behaviour and performance, can be used for optimizing instructional prescriptions (like treatments and sequences) on a refined scale (Beldagli & Adiguzel, 2010). Most micro-adaptive models adjust learning content (structure, presentation, amount) during instruction on the basis of a quantitative representation of learner traits.

No strict borderline between the three approaches exist (Goldberg et al, 2012; Vandewaetere et al, 2011). Many systems have been developed based on interweaving micro-, macro- and ATI-adaptation (Vandewaetere et al, 2011). An example includes a two-stage and iterative approach to adaptive instruction which combined the macro- and the micro-adaptive approach, mentioned in Vandewaetere et al (2011) and created by Tennyson (1993). Initially, an adaptive strategy (macro adaptation) based on pre-task measures, such as cognition, affect and memory was exploited. Then, an intelligent tutoring system delivered constant adjustments of instructional tactics by using procedures sensitive to the student responses (micro adaptation).

Also, the definitions and the descriptions of these approaches in the literature are not clear or they are conflicting. For example, Lee & Park (2008) define the micro-adaptive approach as "allowing different alternatives for choosing instructional goals, curriculum content, and delivery systems, by grouping students" (p. 470) and the ATI approach as "adapting specific instructional procedures and strategies to specific learner characteristics (or aptitudes)" (ibid). The above definitions beget the question: isn't adaptation all about grouping/categorising the users according to certain user characteristics in order to adapt the instruction? Where exactly lays the borderline between these two approaches?

Yet inspection of the literature indicated the following differences among them:

a) The ATI approach is very closely related to the macro-adaptive approach in that it focuses on adapting instructional tactics to individual learner characteristics and differences (Goldberg et al, 2012). Contrary to the macro-adaptive instruction which always tailors instruction before training begins, the ATI approach can also be used to adapt the instruction during training (Landsberg et al., 2010; Goldberg et al, 2012).
b) Contrary to macro-adaptive models which use relatively stable characteristics (like cognitive style) to define which instructional tactics are most appropriate in a given situation, micro-adaptive models are dynamic and use within-task measures or temporal learner characteristics (like motivation level).
c) In contrast with microadaptation, macro- adaptive decisions are domain-independent (Shute, Graf & Hansen, 2005). In the case of content adaptation, what to present is a micro-adaptative decision, and how to best present it is a macro-adaptive decision.
d) the ATI approach deploys more complex and sophisticated user modelling techniques compared to the other two methods.

Yet the ATI approach has received much criticism, such as being too theoretical and time consuming (Mödritscher et al., 2004; Beldagli & Adiguzel, 2010) as well as criticism about oversimplification complex relationships between individual differences and learning outcomes (Vandewaetere et al., 2011). In addition, criticism about ATI studies with limited ecological validity or ATI studies with inconsistent findings and laboratory ATI studies not applicable to actual classroom situations (Lee & Park, 2007). Also, limitations derived from the fact that abilities required by a treatment may shift as the task progresses or from the fact that the abilities assumed to be most effective for a particular treatment may not be exclusive (Lee & Park, 2008).

In addition to the ones mentioned above, some researchers (for example, Mödritscher et al., 2004; Beldagli & Adiguzel; 2010) also suggest another approach, the constructivist - collaborative approach. As its name implies, this approach supports constructivist learning by incorporating in the design suitable mechanisms of knowledge representation, reasoning, and decision-making and collaboration through adaptive grouping. Computer supported collaborative learning can be supported by Web 2.0 tools and social media. On the other hand, collaboration does not happen just because individuals share the same virtual or physical space. Instead, it is required from them to "make a conscious, continued effort to coordinate their language and activity with respect to shared knowledge" (Teasley & Roschelle, 1993, p. 253). Yet, Soller (2001) identified five characteristics of effective collaborative learning: 1) participation, 2) social behaviour, 3) performance analysis, 4) group processing and conversation skills, and 5) primitive interaction. Based on these, she listed components that could be embedded in a collaborative learning system, such as: a collaborative learning skill coach, an instructional planner, a group model, a learning companion, and a personal learning assistant. Such examples are: DSA and PeoplePower which can be seen as a learning companion (Mödritscher et al, 2004).

**Examples of the approaches**

This section discusses examples of the approaches mentioned above**.**

Macro-adaptive approach**:** The macro-adaptive in the oldest of the three already mentioned approaches (Froeschl, 2005). Early macro-adaptive approaches of adaptive learning systems (pre-World War II) are the "Individual Learning Plans": the Dalton plan and the Winnetka plan.

Critical components of latter were: self-paced and self- corrective workbooks, self-administered tests and diagnostic placement tests. Also, the Winnetka plan exploited mastery learning, a behaviourist approach in which students were allowed to move on when pass the test, since this approach advocates that skills must be mastered before learners can go on to master new ones. The role of the teacher was twofold: to organise the important concepts and skills she would like students to acquire into small units of learning and develop a plan of instruction for each student that would enable her to master the objectives at her own pace. Dalton Plan was also focused on learners being able to work at their own pace and supported mastery learning, but the Winnetka plan put greater emphasis on group activities. The "Individual Learning Plans"[5] (ILPs) triggered a school of thought in the American education which stimulated moving from the traditional teacher-led instruction to individualized learning. In both ILPs "classrooms became laboratories or conference rooms and teachers became consultants or guides" (Saettler, 2004, p. 65). Other successful attempts of that time were: the Burk's system of individualised instruction and the Morrison plan. During the 60's and 70's refinements in task analysis procedures, the emergence of criterion reference testing and Gagne's Theory of learning hierarchies[6] (1968) probably affected the development of individualized instruction systems. Perhaps the most well-known system from this period is the "Personalised System of Instruction" or, otherwise called, the "Keller Plan", which was developed at Columbia University (Keller, 1974). It offered personalisation to university students through features like self-pacing and mastery learning with repeated tests that did not used rewards in case of success and punishments/ penalties in case of failure (Keller, 1974). Other well-known and frequently referenced macro-adaptive systems from the 70's are: Program for Learning in Accordance with Needs (PLAN), Individually Guided Education (IGE) and the Individually Prescribed Instructional System (IPI). All these macro-

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[5] It is known that other Individual Learning Plans also flourished, but there aren't enough historical data to describe them.

[6] Originally presented by Gagné at the Annual Meeting of the American Psychological Association, San Francisco, California, and August 31, 1968. It was the presidential address that he presented as retiring president of Division 15 of the Association. Available online at: http://iceskatingresources.org/chapter_2.pdf

adaptive instructional programs mentioned above are representative examples that have been used in educational systems and they have had a common practice in many classrooms for a long time (Mödritscher et al, 2004). The first computer system of Technology Enhanced Learning (TEL) was PLATO- Programmed Logic for Automated Teaching Operations. Developed in the 1960s and 1970s, PLATO is regarded as one of the most successful systems in the history of TEL (Lockee et al, 2007). The Plato Learning Management system, an evolution of the original PLATO system, could provide some rudimental adaptation, in the sense that it could evaluate each student's performance on a test and provide specific instructional prescriptions (Hart, 1981). When mastery of all objectives in the module was reached, the student could proceed to the next module. The first system intentionally designed for adaptive instruction was developed by Ross & Morisson (1988). A salient feature incorporated in this macro-adaptive system was the prediction of student learning needs, however these could be only diagnosed in the pre-instructional phase, not during instruction. In addition to these macro-adaptive characteristics this system also combined some features related to the micro-adaptive approach.

ATI approach**:** Carrier and Jonassen (1988) proposed an eight-step model to provide practical guidance for applying the ATI model to the design of courseware. According to this model, the course designer has to (Park & Lee, 2003; Lee & Park, 2007): 1) identify learning objectives, 2) specify learning tasks, 3) identify relevant learner characteristics, 4) select the most relevant learner characteristics, 5) conduct learner analysis, 6) select differences in the learner characteristics, 7) determine how to adapt the instruction and 8) design alternative treatments. This model resembles the Dick & Carey model (1985) from the Instructional Systems Design (ISD) field. Mödritscher et al. (2004) argued that this model "seems to be the most praxis-oriented within the ATI research, the other ATI approaches are considered to be very theoretical, problematic or time-consuming" (p. 1). A related problem is that only "few studies have provided feasible suggestions for adapting instruction to individual differences" (Lee & Park, 2003).

In addition, Carrier & Jonassen (1988), inspired by Salomon (1972), suggested four adaptation methods based on conceptual mappings between instructional strategies and student characteristics (Park & Lee, 2003; Lee & Park, 2007): (a) remedial actions for providing supplementary instruction, (b) capitalization/preferential actions, for providing instruction in a manner consistent with a student's preferred mode of perceiving or reasoning, (c) compensatory, for supplanting some processing requirements of the learning task (e.g. cognitive processing capacity) and (d) challenge, for motivating students to use and develop new processing modes. Park & Lee (2007, p. 472) argued that although it seems that this model has high practical value, "without theoretically coherent and empirically traceable links among different learner variables and without clearly defined types and levels of learning requirements and instructional strategies for different tasks, the mere application of this model is not likely to produce better results than those of non-adaptive instructional systems", something which it is obvious.

Micro-adaptive approach**:** Early models for the micro-adaptive approach are based on programmed instruction and most recent models apply Artificial Intelligence techniques (Park, 2003). In the bibliography, it is frequently stated that Skinner (1954) was the pioneer concerning programmed instruction, while in fact it was originally introduced by Pressey in 1927, when he created a device that presented a series of multiple choice questions to the student. The student responded by pressing the corresponding key in the keyboard. If the answer was wrong, the device asked the student to choose another answer and if the answer was right, the student could proceed to the next question. If the student answered correctly two successive questions, then the mastery was considered as accomplished and no other questions were prompted to the student (Park & Lee, 2007). Although Pressey's work received much criticism from Skinner (1954), some instructional principles behind it are worth-noting (Park & Lee, 2007): he took into account the difficulty level of the learning objectives and argued that in order to accomplish mastery on the more difficult ones, additional instructional items (i.e. questions) would be required. Although the diagnosis was based on intuition, he concluded from the student's responses whether more instruction was required.

Constructivist and collaborative approaches: Examples of such systems incorporate motivational factors in their design or collaborative activities. The instructional planning can include two constituent components: a content planning for selecting the next learning topic and a delivery planning for shaping how to teach the particular topic. The adaptive e-learning systems that take into account students' motivational factors combine the instructional design with a motivational one. These systems may recognize and increase the levels of student's motivation by incorporating gaze, gesture, nonverbal feedback etc (Mödritscher et al, 2004) to the pedagogical agent or any other mechanism exploited for this purpose. For example, the COSMO system included a life-like animated pedagogical agent whose facial expression, tone of voice, gesture, etc. were dynamically changing in response to its interactions with learners (Lester et al, 1998). Also, this approach included systems that fostered self-regulated learning or students' metacognitive abilities. Cognitive Tutor, was an Intelligent Tutoring System created by a research team from the Carnegie-Mellon University that offered adaptive problem-solving support in two forms, hints and glossary, in multiple levels of detail according the student's specific goal within the problem at hand. The goal of the system was to recognize and increase the students' metacognitive abilities and in particular, their help-seeking behavior (Aleven et al., 2006).

## 2.4 Intelligent Tutoring Systems and Adaptive Hypermedia Systems

For the scope of this thesis, Intelligent Tutoring Systems (ITS) are "adaptive instructional systems developed with the application of Artificial Intelligent (AI) techniques" (Park & Lee, 2003; Mödritscher et al, 2004). ITSs are micro-level adaptive instructional systems since they intelligently diagnose students' learning needs and progress in a response sensitive manner (Lee & Park, 2007; Mödritscher et al, 2004). A paradigm of an ITS which realizes a response-sensitive adaptation procedure proposes a two-level model of adaptive instruction combining micro-adaptive instructions and aptitude variables (Tennyson et al. 1988). First, it allows an expertise module to create conditions based on learner's characteristics. Second, a tutoring module provides dynamic, ad-hoc adjustments of instructional conditions by adapting the amount of information, example formats, display time, sequence of instruction, etc. An example that illustrates that paradigm is the Bayesian adaptive instructional model. First, a computer tutor initiates conditions of instruction based on the pretest performance data. The process for estimating student learning needs exploits a Bayesian probability model. As the process for estimating needs continues, the value of the pretest data becomes less important and recent performance data become more important (Lee & Park, 2007). The efficiency of this approach has been empirically tested.

Adaptive Hypermedia Systems (AHS), inspired by Intelligent Tutoring Systems (ITS), were developed in the early 1990s (ibid). For the scope of this thesis adaptive hypermedia systems are "hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user" (p.88). The AHS model has three main components: data collection, user modelling and adaptation (Beldagli & Adiguzel, 2010). AHSs integrate features both from adaptive learning systems and hypermedia-based systems in the sense that adaptive and user model-based interfaces are built into hypermedia systems (Eklund & Sinclair, 2000). Adaptive hypermedia methods mainly involve two types of adaptation: the adaptive content presentation, and adaptive navigation support. In the latter method, hyperlinks are generated according to different methods like direct guidance, adaptive sorting, annotation, and link hiding, disabling or removal (Brusilovsky, 2000). Examples include the HYPERTUTOR system which hides links that are not relevant for the user's current task, whereas the system ELM-ART generates additionally dynamic links to connect to the next most relevant node to visit. The main limitation of AHSs mentioned in the literature is that often they are not well founded theoretically or empirically (Mödritscher, Garcia-Barrios & Gütl, 2004). Also, De Bra (2000) points out the problem of misguiding the user to irrelevant or not understandable webpages, if prerequisite relationships in the AHS are wrong or omitted. On the other hand, for the successful implementation of an AHS the evaluation the learner's state of knowledge is the most critical factor (Mödritscher et al, 2004). Futhermore, reusability is a problem within the field of AHSs in the sense that it is not straightforward how to reuse the technology of a system for developing another one. To this end, the last decade research efforts are trying to develop adaptation technology for establishing uniform standards (Cristea, 2004; de Assis et al., 2004). The Minerva project was a standardization effort aiming to address the reusability issue by establishing a European platform of standards, guidelines, techniques, and tools for user-model-based adaptability and adaptivity.

Recognising its importance, this thesis attempts to propose a solution for the problem of the absence of theoretical or empirical model, in order to foster mearningful and relevant end-user interactions. In particular, it exploits the theoretical models discussed in the next chapter as well as the empirical model discussed in Chapter 6. These models have informed the design of the adaptive learning environment, as discussed in Chapter 7.

## 2.5 Recent developments of adaptive systems in the eLearning market

In the previous section, a number of adaptive elearning systems were identified and discussed. All of these systems share two characteristics: a) they are not commercial and b) they were created by a university, a research center or a consortium.

On the other hand one could not discern the adaptive eLearning systems that currently exist in the eLearning market (commercial, opensource or freeware) in order to have a holistic idea of the adaptive eLearning systems area. They are described in the section below.

Description of the selection process

The adaptive systems discussed in this section were identified using the Google scholar engine and the default Google engine with the following search terms: "adaptive learning system" + standards-based (without quotes) and "adaptive eLearning system" + standards-based (without quotes) and selecting a timeframe within the last decade (e.g. 2004 onwards). The systems included in the analysis might be in a production phase or in a prototype phase, and, in terms of ownership, they might be freeware, open source or commercial solutions. Only three scientific papers related to the commercial solutions described below were indentified in the literature- Scandura et al, (2013), Mitchell &Howlin (2009) and Lynch & Howlin (2014). The first paper criticizes the conclusions concerning the learning effectiveness of a commercial solution (namely, the Dreambox platform). The second paper by Mitchell & Howlin (2009), discusses the plans concerning the design of a commercial platform, the Realizeit platform, which at that time (2009) was still "a work in progress" (p. 2). The third paper is again related to the RealisedIt platform. Some information was found in white papers (e.g. not published in conference proceedings or journals).

Description of the adaptive learning systems

- Fishtree, https://www.fishtree.com/

It enables teachers to create lesson plans and deliver them online. In terms of adaptive learning, the VARK questionnaire is exploited to diagnose the learning style of the student. Depending on their profile, students get resources to their tailored needs. A mistake made (at least by the time this section was written) on behalf of the platform is that it does not allow the user to select more than one answers while responding to the questions comprising the VARK questionnaire. This may result in a wrong diagnosis of learning style, since all the questions of the VARK questionnaire are multiple selection (not multiple choice) questions. The system tracks the types of activities students prefer (i.e. video-based, text-based, etc.) by measuring engagement time, amount of clicks, and other factors. Using that information and the result of the VARK test, the Fishtree system recommends other learning resources that fit the so-called "Learning DNA" (e.g. the profile) of the student.

- Smarsparrow, https://www.smartsparrow.com/adaptive-elearning/

SmartSparrow is a rule-based adaptive system, enabling the instructors to create branching structures and progression or mastery rules for their content. The system then generates analytics, enabling the instructor to see how students performed (Oxman and Wong, 2014). The system provides adaptive feedback, adaptive content and adaptive sequencing.

- Knewton, http://www.knewton.com/platform/

Knewton was founded in 2008 as a provider of a statistical infrastructure enabling adaptive learning. Its system compares learning success rates associated to particular content and combines that with data about a student's ability level on that content topic to select the most appropriate content (Oxman and Wong, 2014). Knewton platform does not create content, but it can structure it. Knewton's it is an algorithm-based system which allows for less content structuring at the start than others. This data is used to customize content and paths the student may take within the application.

- RealiseIt, http://realizeitlearning.com/

According to Mitchell & Howlin (2009), the system has been designed to "embrace Cognitive load theory and its impact upon Learning Design. Using the Learning Design approaches and standards of IMS Global (IMS-LD) as a foundation, Realiseit is self-intelligent. This provides intelligent flexibility to an individual learner's desired pedagogical (or androgogical) approach" (p .258). Lynch & Howlin (2014) discuss a component of the Realizeit learning environment referred to as Determine Knowledge (DK). This component implements an algorithmic process that aims to uncover the student's latent knowledge. The main assumption adopted in this work is that the mastery of certain knowledge items is necessary in order to begin others (i.e. mastery learning). The set-theoretical framework of Knowledge Spaces forms the basis of this work. In this framework, a curriculum is treated as a graph structure where each node represents an item or a question, and a directed edge between two nodes represents a prerequisite. The DK algorithm begins with all knowledge items having the potential to be part of the latent state. When students are tested on these knowledge items, their response dictates which should be included or excluded. This is repeated until no items are left. The DK algorithm is used at the beginning of every course to uncover the students' latent knowledge so that the student will begin the lesson by pursuing new knowledge.

- Snapwiz, http://snapwiz.com/

This cloud-based adaptive learning platform was launched in 2013. Tutors can create their lessons from scratch using templates and widgets and students can collaborate on their assignments. For the creation of lesson plans content can be harvested by three distinct sources: Open Educational Resources, publisher content resources, or teacher-generated resources. Teachers can also participate in a peer-to-peer collaboration network to share content or request feedback. It provides different facades of learning analytics to educators, students and administrators. For example, students can see an overview of their assignment summaries and they have the option to focus on three key grading areas: recently graded assignments, upcoming assignments, and their overall performance in the class. Process an LTI (Learning Tools Interoperability) integration allows a connection with existing LTI-compliant LMSs. Snapwiz adapts the content being delivered to each student, based on individual needs, learning styles and preferences (http://snapwiz.com/solutions/higher-education/).

- Dreambox, http://www.dreambox.com/intelligent-adaptive-learning/

DreamBox Learning® is a personalized K-8 math environment which has been used at since 2010. Once logged in, students can select their log-in icon (e.g. their avatar), background image and the music they can hear between lessons. A student using the DreamBox program starts its interaction with the program by taking a pretest on the subject matter at stake. The pretest assesses the student's existing knowledge and places him or her at the appropriate knowledge level (Green & Evans, 2014). The system tracks the actions of the student and evaluates the strategies used to solve problems. It then adjusts the level of difficulty, scaffolding, sequencing, number of hints, and pacing as appropriate. The DreamBox platform combines a curriculum aligned to the Common Core and state standards with gamification.

With regards to already well-known elearning platforms, a study (Peter, Bacon & Dastbaz, 2010) evaluated commercial and open source solutions and in particular: Blackboard (http://www.blackboard.com), Intralearn (http://www.intralearn.com/),Saba (http://www.saba.com/products/learning/) Moodle (http://moodle.org), A Tutor (http://www.atutor.ca/ ), Sakai (https://www.sakaiproject.org/ ), LRN (http://dotlrn.org/ ) and Ilias (http://www.ilias.de/ ). The results of this research showed that all of the platforms evaluated "offered very little personalisation and adaptability for the learner. The only personalisation and adapatability offered by the platforms was learning object search and visual preferences setting. No platforms were found to offer personalisation or adaptability based on specific learner needs, goals, behaviour or learning styles" (p.11).

The current situation in the adaptive eLearning market hinders reusability since the ecourses that are created using one of the adaptive platforms mentioned above cannot be transferred and used to another platform. The LMSs mentioned above have established uniform standards that foster the resusablity of ecourses and, also, being open source projects in their majority, they foster the reusability of the tehnology. Yet, as already mentioned, they provide rudimental personalisation.

### 2.6 History of adaptive e-learning from a pedagogical perspective

As one would expect, the development of adaptive learning systems historically follows the philosophical underpinnings of education: behaviorism, cognitivism, constructivism [7] Early research on adaptive e-learning is based on behaviorist approaches, mostly on programmed instruction, in which the instructional materials are divided into associated units of learning.

[7] For the scope of this thesis behaviourism is learning as response strengthening, cognitivism is learning as knowledge acquisition and constructivism is learning as knowledge construction (Mayer, 1992).

Learning the previous unit is a prerequisite for continuing to the next one, and all units are connected sequentially (Juang et al, 2007). Later on, adaptive e-learning and its implementations were affected by cognitivist approaches and, in particular, by the information processing theory which initially emerged in the 1970s and 1980s. In more recent years, while the two other approaches (programmed instruction, information processing theory) are not abandoned in the adaptive e-learning field but revisited, systems that enable collaborative learning, mobile learning, motivational competence and shared control of the adaptation process between the system and the learner have begun to attract the attention of the research community.  One would conclude that these systems mostly follow the constructivist school of thought.

Comparing the different learning paradigms such as behaviourism, cognitivism and constructivism, with respect to adaptive eLearning is a pointless exercise for two reasons: a) effective adaptive eLearning is learner-centered, regardless of the learning paradigm used and b) adaptive eLearning is heavily influenced by the context, which also includes the didactical model used.

Finally, worth mentioning is the interesting work of Gable and Page (1980) who divided teaching design with the modern educational technology into four levels (Juang et al, 2007):  Level one refers to programmed instruction. Level two refers to scrambled textbook exploiting branching strategy. After the student answers a question, the system, in accordance with the student's choice, redirects the learning flow to another unit of learning. Level three pertains to adaptive courseware, which introduces the concept of the adjustable course, in which the branching of the learning flow is not only in accordance with the student's answer on a certain question, but also the combination that refers to the total student performance. Level four is generative, since the instructional materials are analyzed by AI methods, focusing on the student needs in order to generate the most suitable learning flow (Liu & Lee, 1995).

## 2.7 Adaptive learning strategy

### 2.7.1 Critical components

Adaptive e-learning systems consist of three components that together enable instruction which is dependent on the needs of the individual students (or subgroups of students). The names of the components, as used in computer science (with those from educational psychology given in parentheses), are: the domain model (content model), the user model (student model) and the adaptation model, sometimes called the “adaptive engine” (Brusilovsky, 1996; Shute and Towle, 2003).

The content/domain model represents knowledge about (Hospers et al, 2003) the learning objectives, which combine the concepts with the actions that students should be capable of doing (such as remember, apply, etc) and also encapsulates knowledge about the learning activities/tasks (such as exercises, problems etc), as well as, relationships among them. Consequently, it may additionally represent knowledge about workflows, participating roles, etc (Paramythis & Loidl-Reisinger, 2003). The student model represents knowledge about the individual student, such as learning style preferences, demographic data, competence profile (knowledge, skills, attitudes) and other attributes that affect the learning process, like physical or other disabilities (Beldagli & Adiguzel, 2010; Zervas et al., 2011). The adaptation model incorporates a strategy which integrates information from the preceding models. This strategy defines what can be adapted, when and how it is to be adapted (Paramythis & Loidl-Reisinger, 2003). For example, a strategy may involve the selection of learning content to present to the student (Van Seters et al, 2012).

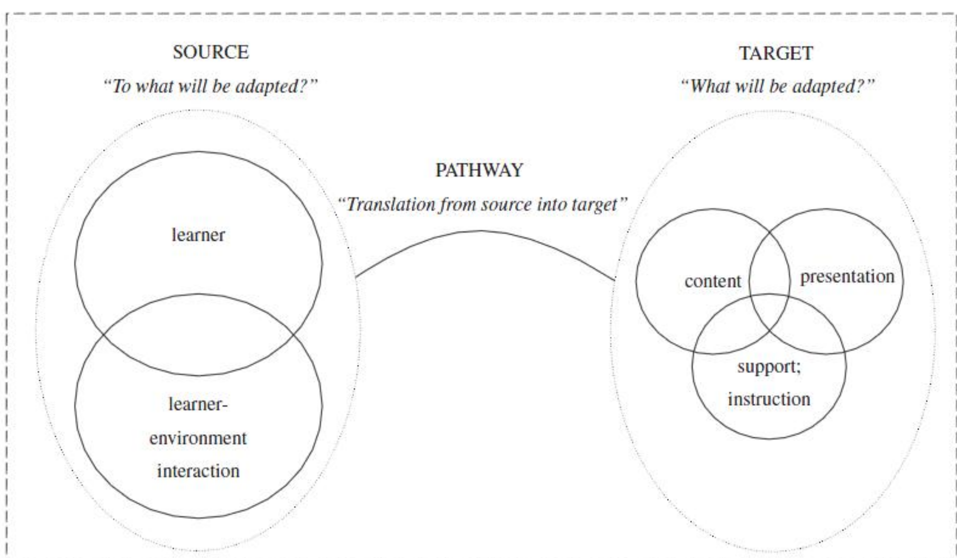


**Figure 2 The learner model [as suggested by Vandewaetere et al. (2011)]**

Vandewaetere et al. (2011) follow similar reasoning using different terminology which is depicted in the figure above, where “source of adaptation” conveys the exact same meaning as “adaptation parameter” and similarly “pathway adaptation” conveys the same meaning as “adaptive strategy”, and, finally, “target of adaptation” is conceptually similar to what Specht and Burgos (2007) named as “adaptation method”. Concerning adaptation methods they refer to one or more of the following (Hook et al., 1996; Melis et al., 2001; Kavcic et al, 2002; Gilbert & Han, 1999) : (a) content (Sun et al, 2007; Jeremic et al, 2009; Reiners & Dreher, 2009), (b) problem solving support and help (Conati et al, 2002; Melis &Andres, 2005), (c) grouping and collaboration (Read et al, 2006), (d) interface and navigation (Conlan et al, 2002; Vassileva & Bontchev, 2006), (e) learning flow and sequencing of learning activities (Hadwin et al, 2007) and (f) information filtering (Germanakos et al, 2008). With regards to adaptation parameters, frequently mentioned in the related literature are (Conlan et al, 2002b; Carver et. al, 1999; Brusilovski, 2001; Hwang et al., 2012): prior knowledge (Ketamo 2003; Graesser et al., 2007), cognitive (Vassileva & Bontchev, 2006; Triantafillou et al, 2004) or learning style (Popescu, 2010), motivation (Fazlollahtabar & Mahdavi, 2009; Beal & Lee, 2005), learner (Vassileva & Bontchev, 2006) or learning (Kelly & Tangney, 2002) goals and others.

Examples of adaptive e-learning strategies (or pathways) include:

- adaptive grouping (target) of students based upon their linguistic knowledge background and performance (sources) aiming to mutual understanding of the collaborative tasks students (Read et al., 2006)
- adaptive content presentation (target) by decomposing each concept into content elements and selective elements presentation based on student’s knowledge level (source) (Jeremic et al., 2009)
- adaptive content presentation via media selection (target) based on student’s cognitive style (source) according to the VARK model, which is presented below (Yasir & Sami, 2011).

### 2.7.2 Types of reasoning

The aim of this section is to provide an overview concerning the types of reasoning behind adaptive e-learning strategies. These types are briefly presented below:

**- rule-based reasoning.** It involves the translation from the source information into the target information, which may occurs by rule-based step analysis, containing ‘if. . .then. . .else ’-rules to determine whether, for instance, a student has mastered a specific knowledge component.

**- agent-based reasoning.** For the scope of this thesis an agent is defined as “an entity created to perform either a specific task or set of tasks”( Giraffa & Viccari, 1998). In Computer Science the term is used for tasks that range from simple system processes to highly sophisticated software or hardware components. A more recent and narrow definition suggests that an agent in the context of Multi-Agent computational models “indicates individual actors modeled as computational objects (e.g., fish in a simulation of a pond ecosystem; vehicles in a simulation of traffic patterns), whose behaviors are governed by simple rules assigned by the user” (Basu, Sengupta & Biswas, 2014, p. 2)

**- fuzzy-logic.** It is considered state-of-the-art (Fazlollahtabar & Mahdavi, 2009; Jeremic et al., 2009), since it involves a flexible method to represent the way human tutors evaluate learners. Since evaluation of human tutors is often not clear-cut, this may entail imprecision, but fuzzy logic can deal with it (ibid).

**- neural networks.** Fuzzy logic can be combined with neural networks. An advantage of neural networks is that they are able to learn from noise or incomplete user data, generalize over similar cases and then use this generalized knowledge to recognize new and unknown sequences or patterns (Fazlollahtabar & Mahdavi, 2009). In learner modeling, neural networks are able to predict learner’s responses and errors. Consequently, they can offer much on adaptive learning, like the opportunity of adaptive learning paths based on students’ predicted responses (ibid).

**- case-based reasoning.** Case-based reasoning is an AI method that is suited to model similarity-based problem solving and learning (Kolodner, 1993; Weber, 1996). Case-based reasoning is a problem solving paradigm that is able to utilize the specific knowledge of previously experienced, concrete problem situations (cases). A new problem is solved by finding a similar past case, and reusing it in the new problem situation. Case-based reasoning is also an approach to incremental, sustained learning, since a new experience is retained each time a problem has been solved, making it immediately available for future problems (Aamodt, 1994).

**-production rules.** A production rule is a condition-action pair. If all the conditions in a production rule are satisfied, then the sequence of actions is executed. Production rules constitute widely used knowledge representations in learning systems (Carbonell et al, 1983). The four basic operation whereby production rules may be acquired and refined are: creation (a new rule is contstucted), generalisation (conditions are made less restrictive), specialisation (additional conditions are imposed so that the rule becomes more restrictive) and composition (two or more rules are composed into a single larger rule). Aleven et al. (2006) built an intelligent tutoring system, Help Tutor, that provides guidance with respect to students' meta-cognitive abilities to help them becoming better learners. The help-seeking model consists of 57 production rules, which capture both correct (or adaptive) and incorrect (or maladaptive) help-seeking behavior. Thirty-two of the rules are bug rules, which reflect deviations from the ideal help-seeking behavior (or "meta-cognitive bugs").

**-Bayesian networks**. A Bayesian network (Pearl, 1988) is a graphical model that encodes probabilistic relationships between variables of interest. Such models help to manage uncertainty, which is necessary in learner modeling on the ground that inferences about the learner's beliefs, abilities, future actions, etc. are exploited (Jameson, 1996). One of the advantages of Bayesian networks lies in its suitability for combining prior knowledge and observed student data. In the case of adaptive learning environments, the prior knowledge consists of the stereotype model that is based upon the learner's goals, tasks and interests etc, whereas the observed data is extracted from the interaction between the learner and the system. The inductive and deductive reasoning capabilities of Bayesian networks support "what-if" scenarios by activating and observing evidence that describes a particular case or situation. Then, the information is propagating through the Bayesian network using the internal probability distributions that govern its behavior (Shute & Zapata-Rivera, 2012).

**-stereotype methods.** A stereotype is a collection of frequently occurring user characteristics. Rich (1983) argued that a stereotype represents a collection of traits in the form of attribute-value pairs and that stereotypes represent structure among traits. A stereotype implies that a collection of traits often occur together, not that they always do (Rich, 1983). Consequently, a rating should be associated with each trait that estimates the probability of the presence of the corresponding trait (ibid). Adaptive methods are used to initially assign users to specific classes (stereotypes) so that previously unknown characteristics can be inferred on the basis of the assumption that they will share characteristics with others in the same class (Kobsa, 1993). Creating stereotypes is a common way of user modeling, whereby a small amount of preliminary evidence is used to assume a large number of assumptions. When more information about individuals becomes available, the assumptions may be altered (Rich, 1983). This is the case of “default stereotyping” in which at the beginning of a session, students are stereotyped to default values, but as the learning process progresses and learner performance data are gathered, the settings of the initial stereotype are gradually replaced by more individualized settings (Kay, 2000).

Approaches like the bayesian networks, fuzzy logic and neural networks are considered as newer to the development of learner models,  compared to rule-based approaches, including production rules and stereotypes. However, it has been argued by Vandewaetere et al. (2011) that “all of these newer techniques are still in the very early stage of development, and none of the techniques has been concretely implemented in an adaptive system”. Also, the pedagogical effectiveness of adaptive learning environments based on these new technologies has not been tested.

## 2.8 Learning styles

A distinction should be made between cognitive styles and learning styles.The former refers to adopting a habitual and distinct mode of acquiring knowledge, whereas the latter can be defined as a habitual or preferred way of processing information (McLoughlin, 1999; James  & Maher, 2004; Mortimore, 2008). The distinction is important since “cognitive style has been seen as the spontaneous almost automatic way in which an individual processes incoming stimuli and learning style is seen more in terms of the strategies a student adopts to cope with learning tasks and situations” (Mortimore, 2008, p.6). Over time, cognitive style is more stable and learning style may be more amenable to changes (ibid, p. 8).

But, what do we mean when we talk about a model of learning style or cognitive style? Mortimore (2008) describes it  through an example: if a researcher is interested in measuring levels of anger, she can measure levels of adrenaline or blood pressure across a range of nerve-wracking situations. She can create a medical model of ‘anger’ in terms of reflex bodily responses.  Alternatively, she can use a questionnaire asking people to rate their anger levels in a 5-point Likert scale of anger intensity in a range of situations. She can then create a different model of ‘anger’ as an emotional, self-reported state. These are just two models of ‘anger’ each of which involves measuring or describing the behavior in different ways. Similarly, when a researcher wishes to measure someone’s learning or cognitive style, she has to decide about the model being exploited (ibid, p.13). Some models are related to brain areas, others are rooted in theories of personality or motivation and some are developmental, following Piaget’s ideas. A question about the selection or the creation of the proper cognitive model may be the following (Mortimore, 2008, p. 14): is cognitive style related to people’s preference to use verbal or visual channels? Is it related to motivation and its effects to learning? Or, to how deeply or superficially people reason? A model may relate to one or more of the following aspects: personality, intellectual development, motivation, self-concept, types of processing, hemispheric specialization (ibid, p. 14)

Learning and cognitive styles typologies were mostly produced by efforts to match instructional presentation, method or materials with the student’s preferences and needs (Park & Lee, 2003). Popescu (2010) acknowledges that although research on learning styles has its origins 30 years ago, the “development of learning style-based adaptive educational systems only started during the last decade”. She also identifies several research challenges on the topic, like contradictory conclusions about the effect of the adaptation of the learning process based on learning styles. That is, some researchers allege the benefits of adaptation based on learning style, like increased performance, increased students’ satisfaction and reduced learning time, while others do not ascertain such benefits. Research challenges related to learning styles in adaptive e-learning include: the selection of the proper taxonomy and the adaptation of the learning styles models to technology-enhanced environments since all of them have been initially proposed for traditional face to face learning (Popescu, 2010).

### 2.8.1 Prominent learning style models

Among those factors that affect the provision of personalised learning contents or paths, learning styles have been recognized as being an important factor (Filippidis and Tsoukalas 2009; Hwang et al, 2012). A content analysis of 70 publications from 2000 to 2011 on adaptive educational hypermedia accommodating learning styles (Akbulut & Cardak, 2012) showed that the most preferred learning style model for research work was the Felder–Silverman Learning Style, which was utilized in 35 studies (50%), followed by cognitive styles: Kolb, VARK, Honey and Mumford and other individual models. They are discussed in the next section.

On the other hand, learning styles have been critisised by some researchers. For example, Kirschner and Van Merrienboer (2013) note that there is no solid evidence that learning styles actually exist and they doubt whether there is any benefit to adapting and designing education and instruction to learning styles. Yet, in their paper the authors do not include a thorough document analysis, like Akbulut and Cardak. The latter conclude that: a) few studies addressed the effectiveness of learning style-based adaptive educational hypermedia, b) one third of the studies provided a framework without empirical evaluation with students, and c) several studies revealed that suggested models influenced student satisfaction and success.

**Kolb experiential learning model**

Experiential learning is grounded on the idea (Kolb, 1984) that learning can be better conceived as an on-going process where our understandings as human beings are continuously reshaped by our experience, as opposed to being conceived in terms of student outcomes. According to Kolb, in the latter case, knowledge is a set of facts or habits as responses to specific stimulus. In this way, learning assessment is being discussed in terms of the newly-accumulated fixed ideas. The definition of the experiential learning process whereby "knowledge is created through the transformation of experience" (Kolb, 1984) was influenced by the idea that "knowing is a process, not a product" (Bruner, 1966).

Inspired by that idea, Kolb has proposed an experiential learning cycle that consists of four modes (i.e. types of abilities) that effective learners need to have:

1. Concrete Experience (CE) abilities, that is, to be able to "involve themselves fully, openly and without bias in new experiences"
2. Reflective Observation (RO) abilities, that is, to be able to "reflect on and observe their experiences from many perspectives"
3. Abstract Conceptualization (AC) abilities, that is, to be able to "create concepts that integrate their observations into logically sound theories"

4. Active Experimentation (AE) abilities, that is, to be able to "use these theories to make decisions and solve problems"

Individual learning styles result from the association of two adjacent modes who are the dominant abilities of the individual (Graf & Kinshuk, 2007):

a. Divergers (CE and RO), they generate creative ideas by viewing situations from various perspectives

b. Assimilators (RO and AC), they create theoretical models by inductive reasoning

c. Convergers (AC and AE), their strength lies in the practical applications of ideas

d. Accomodators (AE and CE), they are actively involve in new experiences; they like to carry out plans and experiments and they often like to take risks

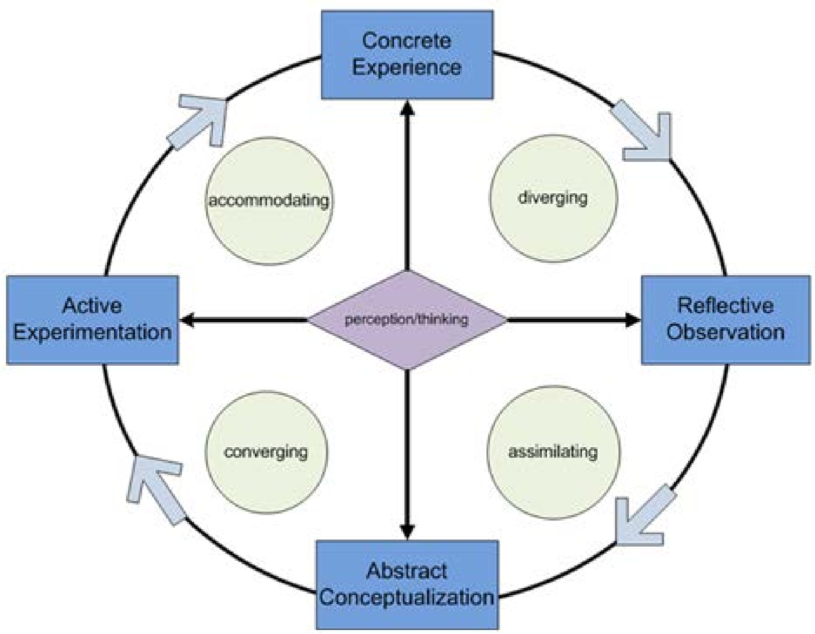


**Figure 3 Model of Kolb's Cycle of Learning and learning styles**
**[figure from the Davenport University Experiential Learning Website]**

Kolb's experiential learning model draws on Dewey', Lewin's and Piaget's work. In particular, it is based on Dewey's (1938) thoughts about the need for learning to be grounded in experience (learning by doing). Additionally, Kolb's model is based on Lewin's model which also consists of four phases: a concrete experience, from which observations and reflections are drawn. They lead to the formation of abstract concepts and generalisations, following which comes the testing of the implications of these concepts in new situations. Finally, Kolb’s model is inspired by Piaget's theory on intelligence as the result of the interaction of the person and the environment: the vertical axis of Kolb’s model represents information perceiving, whereas the horizontal ais represents the processing of information. These two dimensions (information perceiving and information processing) are grounded in the cognitive development work of Jean Piaget. For Piaget (1970), experience and concept, reflection,and action, as well as, the shift from a phenomenal view of the world to an abstract constructionist view to a reflective interlined mode of knowing, form the basic continuum for the development of adult thought.

Kolb developed the Learning Styles Inventory, a brief and self-report instrument based on the four modes of learning styles, meant to “describe general patterns of individuality in learning” (Yim, 2009, p. 3). When a student takes the LSI, they will fall into one of the four learning styles.

**Peter Honey and Alan Mumford's model**

Based on Kolb's experiential learning model, Honey and Mumford (1986) suggest a similar categorization of individual learning styles (Honey & Mumford, 1986; Graf & Kinshuk, 2008) :

1. Activists, similar to Accomodator, who are active learner are well equipped to experiment and enthusiastic about anything new
2. Reflectors, similar to Diverger, prefer to learn from activities that allow them to review their experiences from many perspectives and think things over; also, they might like to observe others and their experiences
3. Theorists, similar to Assimilator, who prefer to learn through problems that allow them to conclude through a step-by-step process or by integrating observations of models and facts into theories
4. Pragmatists, similar to Converger, who prefer to learn through practical knowledge and real-world applications that allow them to plan how it can be applied to actual practice and try out ideas, theories or techniques.

The Honey & Mumford model can be conceived as an adaptation of Kolb’s model in which the stages in the cycle were renamed so as to align with managerial experiences of decision making and problem solving. Also, the learning style modes reflect in this model adaptable preferences rather than personality characteristics.

**VARK (Visual-Auditory-Read/write-Kinesthetic) model**

The VARK (an acronym Visual, Aural, Read/Write and Kinesthetic learning style modality) model defines one's sensory modality preference(s). According to its creator, N. Fleming (2001) learning style can be defined as "an individual's characteristics and preferred ways of gathering, organizing, and thinking about information. VARK is in the category of instructional preference because it deals with perceptual modes" (p. 1). Since it deals with perceptual modes and taking into account the above definitions about cognitive and learning styles and their distinction between them, the VARK model is not a learning style model but a cognitive style model. Yet, since the creator itself names it learning style model and it is also frequently met in the bibliography (for example, in Hawk & Shah, 2007) as a learning style model, this assumption will also be adopted in this thesis. The VARK questionnaire is freely available online and it has two versions: one for adults8 and one for younger people9, each one comprised by 16 multiple selection questions. The VARK Inventory provides metrics in each of the four perceptual modes, with individuals having preferences from one to all four. The popularity of the instrument comes from its validity, its simplicity, its ease of use, and the wealth of learning materials that have been designed to accompany it, among others: maps, charts and diagrams, flowcharts, highlighters, different colors s for the visual type, text, lists, essays, reports, note taking for the read/write type, oral explanations, spoken lessons and discussions for the aural type. Kinesthetic individuals prefer to learn through direct practice/hands-on approaches, real-life examples, field trips, trial and error which may also involve the other perceptual modes (Leite et al, 2010; Svinicki & Shi, 2010; Hawk & Shah, 2007).

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[8] http://www.vark-learn.com/english/page.asp?p=questionnaire

[9] http://www.vark-learn.com/english/page.asp?p=younger

**Felder–Silverman Learning Style Model**

The Felder–Silverman Learning/Teaching Style Model (Felder & Silverman, 1988), originating in the engineering education field, is in line with the assumption that A learning-style model classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information (Felder & Silverman, 1988, p. 674).

The Felder-Silverman model asserts that individuals have preferences along five bipolar continua:

- the Active- Reflective, based on how the student prefers to process information; the former type through engagement in physical activity and/or discussion and the latter type through introspection
- the Sensory (external information)-Intuitive (internal information), based on the type of information that the student preferentially perceives; the sensory type prefers sights, sounds, physical sensations etc., whereas the intuitive type prefers to think about possibilities, insights, hunches etc.
- the Verbal-Visual, based on the sensory channel through which external information more effectively perceived
- the Sequential-Global, based on how the student progresses toward understanding, in steps or holistically
- the Intuitive-Deductive, based on the organization of information with which the student feels more comfortable; the former type prefers facts and observations in order to infer underlying principles and the latter type prefers principles in order to deduce consequences and applications

The Index of Learning Styles[10] (ILS) is a self-scoring web-based instrument that assesses preferences on the Sensing/Intuiting, Visual/Verbal, Active/Reflective, and Sequential/Global dimensions. It is available free for teaching and research purposes, and it is licensed for commercial purposes.

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[10] http://www.ncsu.edu/felder-public/ILSpage.html

### 2.8.2 Adaptive learning platforms that incorporate learning styles

This section includes examples of how systems were designed to incorporate learning styles as part of the personalisation offered by them. The first example is the e-learning platform iLearn (Peter, Bacon, & Dastbaz, 2008), which is an ontology-based system that provides relevant learning resources as a personalised e-learning package for the learner. According to Peter et al (2008), one of main reason why VARK was selected was due to the fact that it was found that this learning style typology/categorization compared to the others can also be clearly mapped to the different types of learning materials. In the case of the iLearn platform, the VARK learning style typology was used to select the relevant material for each learner based on their learner type. Fleming's (i.e the creator of the VARK questionnaire) actual recommendations for the appropriate study strategies were associated with types of learning objects represented within iLearn.

Studying learning styles with a view to applying them in practice in physical or virtual classes must take into account available and potential educational material and methodologies. No matter how correct is an in-depth psychological analysis of learning styles, it is useful in practice only if (a) a teacher or an e-system can apply it in reasonable time and (b) there exist learning materials and methodologies which differentiate accordingly. Otherwise it can be a (perhaps) very interesting study of learning of only theoretical value.

In the AHA! adaptive application (Stash et al., 2006) adaptation strategies for the following learning styles: Active versus Reflective, Verbalizer versus Imager, Holist (Global) versus Analytic, Field-Dependent versus Field-Independent (FDvsFI) were pre-defined by the developers and the correspondingly appropriate learning style typology could be selected ad-hoc by the authors of the adaptive e-courses.

CooTutor (Coordinate Tutor) is a web-based tutoring system whose mechanism of adaptive material selection took students' different spatial ability and learning styles into account, and performs traits-based personalisation of learning experience (Wang et al, 2004). CooTutor aimed to personalise its presentation adaptively to fit individual differences, including knowledge status and individual traits (i.e., spatial ability and learning styles). This research focused on using the styles matching strategy to accommodate students' traits. The strategy was to adapt the content or structure of the instruction with proper pedagogical/teaching styles to match students' learning styles. CooTutor adopts the strategy of styles-matching as well. The Felder-Silverman learning styles model used in this research has formulated these pedagogical styles to cope with different type of learning styles.

LearnFit is a personalised e-learning system in the form of an add-on to the popular Moodle Learning Management System to provide adaptivity and a learning experience which took the student's personality into account. In this system modules for personality recognition and selection of the appropriate teaching strategy are used to enhance the learning process. The Myers-Briggs Type Indicator's model was adopted "as one the well-known source information for personalisation" (El Bachari et al, 2011).

INSPIRE (Papanikolaou et al, 2003) was an Adaptive Educational Hypermedia prototype in which dynamically generated student-tailored lessons gradually lead to the accomplishment of learning goals. The learning style model of Honey and Mumford has been adopted as the basis of determining the presentation of the educational material on each of the performance levels (Three levels of student performance are defined in accordance with the Component Display Theory).

Adaptive Personalised eLearning Service (APeLS), a personalised eLearning service using the multi-model, metadata-driven approach for producing rich adaptive eLearning solutions that remain content and domain independent (Conlan & Wade, 2004). Through this independence, the eLearning services developed can utilize many pedagogical approaches and a variety of models to produce a wide range of highly flexible solutions. APeLS use the VARK, Kolb, Honey and Mumford models (Peter et al, 2010).

eTeacher (Schiaffino et al., 2008), an intelligent agent that provides personalised assistance to the students. In particular, eTeacher observes a student's behavior while she is taking online courses and automatically builds her profile, which comprises her learning style and information about her performance. Through the use of Bayesian networks, the student's learning style is automatically detected from her actions. The information contained in the student profile is used to assist her by suggesting personalised courses that will help. The eTeacher system incorporated the Felder and Silverman model.

On the other hand, the developers of the SCRAT system (Germanakos et al, 2009) argued that "learning style theories that define specific types of learners, as Kolb's Experiential Learning Theory, and Felder/Silverman's ILS have far more complex implications, since they relate strongly with personality theories, and therefore cannot be adequately quantified and correlated easily with Web objects and structures". They used Riding's Cognitive Style Analysis (Riding & Cheema, 1991) in the learning style dimension of their Data – Implications Correlation Diagram, in order to filter the raw content and deliver personalised Web-based result to the user.

## 2.9 Tools for the creation of standards-based adaptive eLearning courses

The ReCourse LD editor (http://tencompetence-project.bolton.ac.uk/ldauthor/) uses a combination of visual (for the level A) and form-based (for the level B) user interface. It is a second generation IMS-LD tool and it is the visually improved successor of its predecessor, the Reload IMS LD editing tool. Dodero, del Val and Torres (2010) claim that usability improvements "include a visual overview of the flow of activities in a UoL, drag and drop facilities to define relationships between elements of the LD, and a generally improved interface design". However, "providing a visual metaphor for level B properties and conditions is still an issue" (Dodero, del Val & Torres, 2010).

CADMOS (Courseware Development Methodology for Open instructional Systems, http://cadmosld.com/) is a graphical IMS-LD Level A and B compliant learning design (LD) tool, which promotes the concept of "separation of concerns" during the design process, via the creation of two models: the conceptual model (which describes the learning activities and the corresponding learning resources), and the flow model (which describes the orchestration of these activities). According to the feedback from an evaluation case study with 36 participants, reported in this paper, CADMOS is a user-friendly tool that allows educational practitioners to design flows of learning activities using a layered approach. CADMOS supports the "separation of concerns" notion in the LD process. CADMOS contains three different types of rules (Katsamani & Retalis, 2013): the "User Choice" rule (i.e. the user indicates the end of an activity), the "Time Limit" rule (an activity is completed by a specific time), the "Score Condition" (if–then–else) rule which defines which activity is next if the score of the previous activity is above a threshold or not.

The GLM tool (Graphical Learning Modeller, http://sourceforge.net/projects/openglm) is an editor that provides graphical support conformant for the creation of IMS-LD Units of Learning (level A and/or level B). It hides Level B elements inside interactions or add-ons, which can be used to create predefined evaluation activities (for text work, uploading files, question and answers and multiple-choice tests). This approach is similar to the LAMS (Learning Activity Management System) tool, but limited to four types of activities. Both GLM and LAMS require the defining of a new add-on or tool for each new type of activity requiring assessment (Dodero et al., 2010). Its main goal is to provide support for designers by converting a graphical representation of a learning design to the required XML format, as specified the IMS-LD standard (Prieto et al., 2013).

### 2.10 Adaptive feedback

Adaptive feedback is a form of adaptive scaffolding[11] mostly related to the student's help and support. As one would expect, the advances in the computer-bases adaptive feedback are in line with the educational movements. Consequently, initially it revolved around primitive behaviorist approaches and the reward-punishment dipole. The emergence of information-processing theory provided new lens through which students'errors can be seen primarily as a source of information about students' cognitive processes, as well as, an expected part of the learning process (Mason & Bruning, 2001).

Feedback entails three main factors (Narciss and Huth, 2004; Shute, 2008): (a) the content (evaluative and informative aspects), (b) the function (cognitive, metacognitive, motivational), and (c) the presentation (timing, schedule and/or adaptivity considerations). In regard to the

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[11] For the scope of this thesis the term scaffolding is defined as "the process by which a teacher or more knowledgeable peer provides assistance that enables novice learners to solve problems, carry out tasks, or achieve goals, which would, otherwise, be beyond their unassisted efforts" (Wood et al. 1976 referenced in (Basu, Sengupta, & Biswas, 2014)).

cognitive function of the feedback, researchers (e.g., Bangert-Drowns et al., 1991; Mason & Bruning, 2001) converge that effective feedback (feedback that facilitates the greatest gains in learning) should provide the student with two types of information incorporated into the item response: verification and elaboration. Verification is the confirmation of whether an answer is correct or not, while elaboration provides relevant cues to guide the student towards a correct answer. It may explain why the selected response is wrong and indicate what the correct answer is.

Commonly used types of feedback can be summarized as follows (Mason & Bruning, 2001; Gouli et al, 2006; Shute, 2008):

- Knowledge-of-response informs the students whether their answers are correct or not.
- Answer-until-correct requires the student to remain on the same test item until the correct answer is selected.
- Knowledge-of-correct-response supplies students with the correct answer.
- Topic-contingent feedback obliges redirecting students to passages or other learning material where the correct information is located, if they answered incorrectly. Or, they are presented with extra instructional material from which they may find the answer.
- Response-contingent feedback provides knowledge of the correct response and gives response-sensitive feedback which explains why the incorrect answer was wrong and why the correct answer is correct.
- Bug-related feedback provides verification, relies on “bug-libraries” and assists students in identifying procedural errors, often aiming at self-correction.
- Attribute-isolation feedback provides item verification and focuses on the central attributes/key components of the target concept to improve general understanding of the phenomenon studied.

Shute (2008) also includes hints, cues and prompts (feedback guiding the learner in the right direction) as well as, bugs and misconceptions (feedback requiring error analysis and diagnosis) while avoids to mention the terms bug-related feedback as such. There is growing consensus in the literature that response specific feedback seems to enhance student achievement more than other types (Corbett & Anderson, 2001; Mory, 2004; Shute, Hansen, & Almond, 2007; Shute, 2008).

Also feedback can be characterized in various other ways:

- task-level feedback (which provides more specific and often real-time information) as opposed to general summary feedback
- directive feedback (which tells the student what needs to be fixed or revised) as opposed to facilitative feedback (which provides comments and suggestions to help guide students' own revision and/or conceptualization)
- delayed or immediate feedback
- specific or general feedback (i.e. general advice)

Feedback can provide information that may be useful for correcting inappropriate task strategies, procedural errors, or misconceptions (Mason & Bruning, 2001; Mory, 2004; Narciss & Huth, 2004; Shute, 2008). The corrective function seems to be more effective when feedback is specific (Baron, 1988; Shute, 2008). Also, elaborative feedback can (among others): address the topic or the response, discuss the particular error(s), provide worked examples or gentle guidance. The first three types of elaborated feedback are more specific and directive, and the last two types are more general and facilitative.

On the other hand, researchers who performed meta-analyses on the feedback data use descriptors such as "inconsistent," "contradictory," and "highly variable" to describe the body of feedback findings (Shute, 2008). About one third of the studies reviewed in two landmark meta-analyses reveal negative effects of feedback on learning (ibid). In addition there are practices that are to be avoided, such as, when a student is actively engaged in problem solving and interrupted by feedback from an external source, this been shown to hinder learning (Corno & Snow, 1986; Shute, 2008). There also good practices, such as, providing feedback which is specific and clear for conceptual and procedural learning tasks (Shute, 2008).

In reality, feedback is a complex issue that can be seen from various perspectives. The Artificial Intelligence research community approaches feedback with the use of reinforcement learning mechanisms which handle the assignment of penalty or credit in different situations in order to know the value of a situation in relation to a final goal.  Such an application is mentioned in Kalles and Fykouras (2010) where the computer serves as the student and the goal is to find examples of effectively tuning the "syllabus". The rationale is that capturing a human's playing attitude primarily entails developing satisfactory infrastructure to codify and store that "attitude".

## 2.11 Literature review on overcoming  students' misconceptions via computer supported means

**Description of the selection process**

The literature review was conducted via typing in the Google scholar search engine the following combinations of keywords: "adaptive learning"+ "student misconception", "personalised learning" + "student misconception", "adaptive instruction" "student misconception" "personalised instruction" +"student misconception", "personalized learning"+ "student misconception", "personalized instruction"+ "student misconception", "adaptive learning" + inherent difficulties content (without quotes), "personalised learning" + inherent difficulties content (without quotes), "personalized learning" + inherent difficulties (without quotes).  In each of the above search attempts, judging from the title and the short description of the paper, I decided whether she should read the abstract and the introduction of the paper[12]. A paper was included in the literature review provided that it contained a section with empirical results and it was actually relevant to the topic of this study. Six research papers were identified and they are presented below. They are dated from 2008 onwards.

**Literature review**

The description of the research efforts presented in the papers included in the literature review is discussed in brief below.

[12]I could access open-access papers and also access was provided via the OpenAthens service http://www.openathens.net/resources.php

1. The adaptive learning system suggested by Heh, Li, Chang, Chang & Liu (2008) diagnoses and identifies the students misconceptions using a knowledge map. The system selects suitable learning materials that address the students' misconceptions, provides remediation by arranging a learning path for students and provides feedback about suitable for them teaching materials. This research uses precision, recall, and F-measure for the effect measurement of the recommended materials (Van Rijsbergen, 1979). Precision indicates the accuracy rate of selected teaching materials, recall is the degree of coverage of the concepts in teaching materials that are part of the student's misconception (Kowalski, 1997; Van Rijsbergen, 1979), and the F-measure is a harmonic mean of precision and recall. The results show that the learning materials and the learning paths suggested by the system are good. Throughout the learning diagnosis the subject matter expert sets a misconception threshold for each concept in the test to diagnose whether the student misunderstands a concept or not. When a value exceeds the threshold, the concept is said to be a misconception. The thresholds are given by the subject matter expert. The thresholds are used to determine which teaching materials are suitable to recommend to the student. The authors concede that the degree of understanding of a concept in a test is not easy to measure, since a test usually contains more than one concept. For example, the concept of the "free-falling object" is based on the concepts of acceleration and gravity. In dealing with concepts the authors make three assumptions, that: 1. student obtaining the wrong answer implies that she missed some relevant concepts, 2. the concept in the upper (more abstract) level involves concepts in the lower (more specific) level in the concept hierarchy of knowledge map and 3. when a concept becomes a barrier to the student, the concepts below it also become barriers to her.

2. The study suggested by Chen (2014) proposes an adaptive scaffolding system that supports the student's cognitive and motivational needs. It uses the Vygotsky's Zone of Proximal Development (1978) and Brophy's (1999) zone of motivational proximal development (ZMPD) theories. These theories serve as the basis for dynamically modeling learning characteristics and for designing instructional materials. Also, the Self-determination theory (SDT) (Deci & Ryan, 1985; Ryan & Deci, 2002) is used. It is a general theory of motivation which theorizes human motivation into three main categories: intrinsic motivation, extrinsic motivation, and amotivation. These categories are mapped with types of scaffolds used in the system's motivational scaffold

model. This model uses artificial intelligence techniques to dynamically diagnose learners' motivational levels (i.e. 1, 2, and 3). The system uses this information to determine what type of scaffold to present next to the student. In the context of this research, scaffolds are text-based messages that encourage the regulation of learning and address the importance or relevance of knowledge to the learners. Chen conducted an experiment concerning the concepts of velocity and acceleration. The study revealed a relationship between students' prior knowledge and learning outcome when using adaptive scaffoldings, whereby students with lower levels of prior knowledge demonstrated greater levels of improvement in their learning outcome than those with medium to high levels of prior knowledge. Finally, the results suggested that learners with lower levels of knowledge who possessed extrinsic motivation benefited the most from the adaptive scaffolds.

3. The rationale of the approach adopted in the "Affinity" system (Zygielbaum & Grandgenett, 2001) differs from the approach described in the point 1 above. In order to describe the philosophy of providing support and help to the students, the authors use the "teaching how to bike" metaphor. They suggest that teaching a child to ride a bicycle, involves breaking the instruction down into relatively small lessons. Each lesson consists of an activity and an assessment. For example, one might demonstrate the handlebars by showing them to the child and explaining how the bike can turn by using them. The child is then asked the purpose of the handlebars. If the response is that they cause the bike to turn, then the teacher can proceed on to the pedals. If the child responds that the handlebars cause the bike to go faster, then some remedial activity is needed. In the context of this work, remediation could be an enhancement, or presentation in greater granularity (i.e. level of detail).

4. The "Click" service (de la Chica, Ahmad, Sumner, Martin, & Butcher, 2008), which is a digital library service, provides personalized instruction by integrating digital library resources that support the evolution of student conceptual understandings of science content. This happens through the personalized selection and presentation of educational resources from digital libraries. Similarly to 1, knowledge maps are used to understand and encode the macro-level structure of an information space (i.e. knowledge domain). "Click" analyses students' artifacts (e.g., student concept maps) to generate a student knowledge model which depicts their existing

conceptual understanding. In its conceptual framework, “Click” compares the domain competency model to the student knowledge model to identify conceptual gaps and select a student-appropriate response.  “Click” selects and presents relevant digital library resources to the student to promote improved understanding in the identified areas. The “Click” conceptual framework considers the adaptive instruction as a dialogue between the system and the students, based on Laurillard’s 'conversational framework' for describing the essential aspect of the learning process. That is, it should be: discursive, adaptive, interactive and reflective (de la Chica, Ahmad, Sumner, Martin & Butcher,  2008).

5.  In AdaptErrEx (Goguadze, Sosnovsky, Isotani  & McLaren, 2011), based on the results of a literature review conducted by the authors, the most frequently occurring misconceptions about decimal numbers were identified. Then, in an attempt to structure the rationale behind the students’ incorrect responses to decimal problems and to provide a means for diagnosing students’ learning difficulties, the researchers organised these misconceptions into a taxonomy. In order to account for dependencies between misconceptions, a Bayesian Network (BN) was built, in which each misconception is represented by a probabilistic node with two possible alternatives (present/absent). Taxonomic relations between the nodes are accompanied by conditional probabilities. In the figure below, *Regz* represents the misconception “*decimals are treated as regular numbers*”. Such a misconception can lead to solutions like 0.08 > 0.2 where students ignore leading zeros, as with “regular” integer numbers. *Megz* represents the misconception “*longer decimals are larger*” which can lead to solutions like this: 0.234 > 0.62. Another node type in the Bayesian Network is the evidence nodes which represent problems. They are the bottom nodes in the taxonomy shown in the figure below such as Easy-Regz-T1 and Megz-T2. The evidence nodes can be connected to one or more misconceptions and contain a number of alternatives. Each alternative corresponds to a possible answer the student might give to the problem.

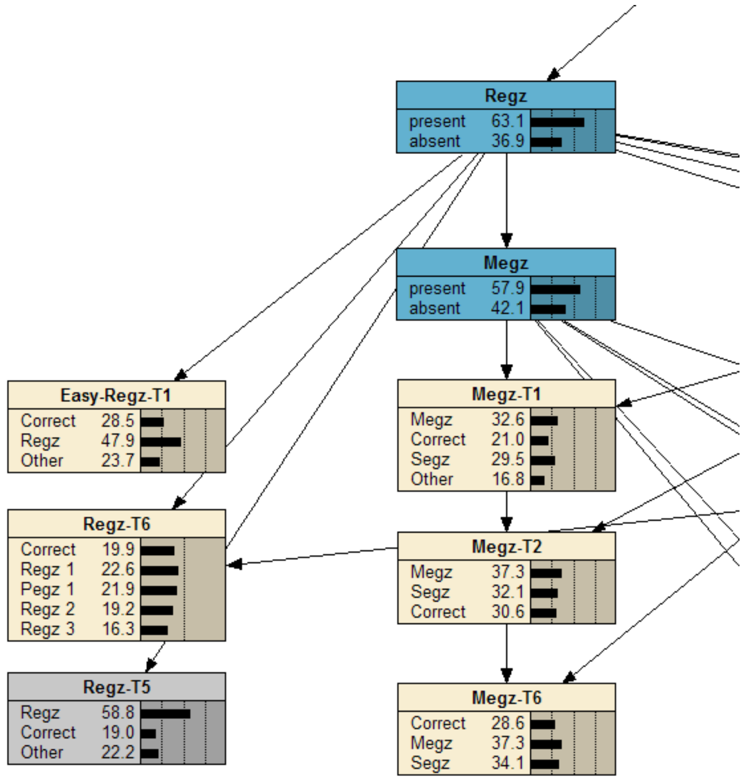


**Figure 4 Bayesian network of students' misconceptions in AdaptErrEx [taken from (Goguadze, Sosnovsky, Isotani, & McLaren, 2011)]**

Every alternative evidence node is probabilistically connected to the corresponding alternative misconception nodes. This means that presence/absence of a misconception influences the likelihood of a student giving a certain answer to the problem. For example, in the case of the problem *Megz-T6:* if the student chooses the second option as an answer she produces evidence of having the misconception *Megz* described above, whereas the third alternative is evidence for a different misconception – *Segz*, which is present when a student thinks that shorter decimals are larger. The alternative node labelled as *Correct* represents the correct answer and contributes negatively to the presence of all the misconceptions of a given problem. Finally, the node labelled as *Other* represents any incorrect answer not known to be connected to any misconception of a given problem.

6. OLMlets (Bull & Gardner, 2010) aims to provide formative assessment opportunities for students using an adaptive approach that maintains focus on the student's understanding. Multiple-choice questions and the corresponding response options are provided by the lecturer(s),

including options that indicate students' common misconceptions (Bull et al., 2006). The skill meters show the extent of understanding of a topic (green – indicated by medium shading in Figure 5).

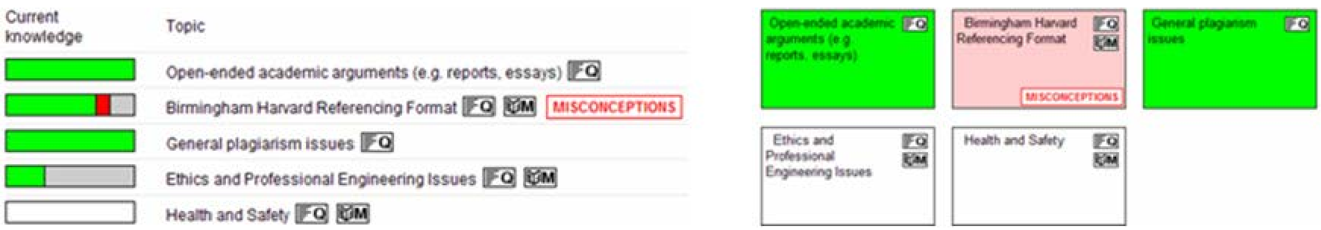


Figure 5 The OLMlets skill meters and boxes[taken from Bull & Gardner (2010)]

The skill meters indicate the extent of 1) current understanding of a topic (in green) and 2) misconceptions in the topic (in red). More general lack of knowledge or difficulties not linked to specific misconceptions are shown in grey (light shading). White (unshaded) indicates insufficient data to model the student's level of knowledge of a topic. Whenever misconceptions are inferred, students obtain a brief text description of their misconception(s) by clicking on the "MISCONCEPTIONS" link (Bull et al., 2008). The 'boxes' views on the right side of Figure 5 illustrates the same information by colour. The 'Q' icons lead to questions and 'M' to learning materials. OLMlets Learner Models are inferred based on the user's last five attempts at questions on each topic, dynamically updating with greater weighting on the most recent of these latest five attempts. Thus the Learner Models always represent current knowledge states (Bull et al., 2008).

## 2.12 Learning Design and IMS-Learning Design

### 2.12.1 Definitions

In the recent literature, the meaning of Learning Design is twofold (Conole, 2008; Donald et al., 2009) since it can be viewed both: a) as a process of designing for learning (i.e. lessons, learning activities, lesson plans) and b) as a product that contains elements such as descriptions of learning tasks, resources and scaffolds. Dobozy (2011) expands this typology by adding the notion of Learning Design as "a standardised (re)presentation of technology enhanced learning sequences and prescribed design based procedures that are content independent". In (Conole, 2008) it is stated that the term in recent years is being used almost synonymously to "course design".

Durand and Downes (2009) defined learning design as “the description of the teaching-learning process that takes place in a unit of learning (e.g. a course, a lesson or any other designed learning event)” (p. 894).  For the scope of this thesis, LD is defined as "the act of devising new practices, plans of activity, resources and tools aimed at achieving particular educational aims in a given situation" (Mor and Craft 2012).

Closely associated with the concept of LD are “the implementations of the concept made by the IMS-Learning Design (IMS-LD), as well as, the technical realisations around the implementation of the concept” (Durand & Downes, 2009, p. 1). From this perspective, the Learning Design specification is a notational system which IMS-LD compliant editors and players employ, along with instructional engineering methods (Paquette & Marino, 2006), in order to create a Learning Design for sharing and future re-use (Kordaki, Papadakis & Hadzilcos, 2007).

IMS-Learning Design (IMS GLC,2003), a de-facto elearning standard, is a pedagogically neutral specification in that it provides a formalization of the teaching-learning process through the metaphor of the theatrical play comprised of actors, roles and sequences of activities (Jeffery et. al, 2005), leaving all the pedagogically vital decisions, such as teaching strategies, learning objectives etc, to the instructional designer and allowing various kinds of learning strategies to be expressed. Moreover, IMS-LD is especially designed for web-based learning and facilitates interoperability among LD systems and tools, since it provides a platform-independent notational convention to allow sharing and re-use of the learning designs (Britain, 2007). It enables reusability of a learning design (i.e. learning scenario) as a whole or parts of it (Jeffery et al, 2005). LD provides a generic and flexible language, a version of which is set out in the IMS- LD specification, that aims to describe “who does what, when and with which content and services in order to achieve certain learning objectives” (Kopper, 2005). IMS-LD was initially launched by IMS Global Learning Consortium (IMS GLC, 2003).

### 2.12.2 The IMS-Learning Design

The information model of the IMS-LD (IMS GLC, 2003b) has three levels of implementation, each a superset of the precedent one:

- Level A provides the core elements of the modelling language (roles, activities, services, resources etc)
- Level B adds properties and conditions and serves as the adaptation basis since, in its simplest form, enables the creation of rule-based (simple "IF-THEN-ELSE" rules) adaptation: an event is triggered when a property satisfies a condition. For example, the average grade of the student ("property") is calculated ("event") when the last question of a quiz is answered ("condition"). Adaptation rules are created by the designer during authoring time of the resulting Unit of Learning (i.e. the adaptive course)
- Level C adds notifications, both between system components and the participating roles of the learning process. "Activities can be set as a consequence of dynamic changes to the learner's profiles and/or of events generated in the course of the learning activities. It can also be used to trigger messages being dynamically sent to participants. This enables the automation of learning flow activities, which may be triggered by the completion of tasks, rather than the learning flows being pre-determined" (IMS GLC, 2003).

Like other eLearning standards (like SCORM which based on IMS Simple Sequencing), IMS LD realises an approach of content packaging. The packages contain the learning resources (data or services), as well as, the accompanying metadata. The creation process of IMS-LD course packages has received criticisms (Dietze et al, 2007) because the learning resources are allocated at design-time, when the actual learning context is not known and this limits re-usability. This limitation is also true for the SCORM packages though.

### 2.13 Broadening the use of e-learning standards for adaptive learning

The table below depicts the adaptation types that can be fully or partially implemented with the use of the IMS-LD methodology (Burgos & Barak, 2009; Burgos et al, 2006):

Table 1 Support levels of the adaptation methods

| Method of adaptation | Related to… | Level of support |
|---|---|---|
| Interface-based adaptation | elements of the graphical user interface | None |
| Learning-flow adaptation | the sequence of the learning activities | Full |
| Content-based adaptation | changes of the actual content | Full |
| Interactive problem solving support | guidance that helps the user to take a step further in solving a problem | Full |
| Adaptive information filtering | appropriate information retrieval | None |
| Adaptive user grouping | ad hoc creation of user groups | Partial |
| Adaptive evaluation | changes (of the actual content etc) based on student's performance | Partial |

The IMS-LD specification was frequently used as the modelling basis for adaptation and personalisation (Burgos et al., 2007; Paramythis & Loidl-Reisinger, 2003; Magnisalis & Demetriadis, 2012; Specht & Burgos, 2007) in a range of TEL examples that include: an adaptive learning management system (Boticario & Santos, 2007), authoring tools to define re-usable adaptive learning designs (Berlanga & García, 2005; Miao, 2005; Sampson et al., 2005), adaptive learning designs (De-la-Fuente-Valentín et al., 2011; Berlanga & García, 2005; Burgos et al., 2007; Mavroudi & Hadzilacos, 2012(a),(b)), Computer Supported Collaborative Learning (Hernández-Leo et al., 2006; Valdivia et al., 2009; Magnisalis & Demetriadis, 2012).

One of the first attempts towards providing personalised web-based learning through the use of IMS-LD compliant Units of Learning is being described in Towle and Halm (2005) where the following adaptation strategies are discussed:

- Using different communication and interaction channels such as synchronous interactions (chat) for extrovert learners vs. asynchronous interactions (forum) for introvert learners.
- Deploying different cognitive strategies, such as deductive (rule–example) vs. inductive (example–rule). Exploratory learners may benefit more by concepts being introduced through examples, whereas for other learners a definition may be the effective introduction of a new concept.
- Exercise different levels of learners' encouragement. This was a strategy "where the feedback a learner receives is tailored to their learning orientation" (Towle & Halm, 2005).

A significant advantage of using the IMS-LD specification for adaptive learning is that there is no need to re-create the runtime environment for the adaptive courseware, since this infrastructure is implicitly inherited in any IMS-LD compliant player (Towle & Halm, 2005). Accordingly, there is no need for the developers of the adaptive courseware to bind themselves with a particular authoring tool: any level-B compliant IMS-LD editor will do. Level B provides the key functionality for adaptation in Learning Designs, namely properties and conditions. More specifically, it enables a simple "key-value pairs" (like "Age"= 33) type of adaptation (Baldauf et al., 2007) through mappings (rules) between properties and conditions.  An example of such an adaptation rule might be the following: "If the learner is familiar with the topic, then show activities X, Y and Z else show activities B and W". In order to implement such a rule in the context of an IMS-Learning Design compliant Unit of Learning (UoL), the instructional designer should perform the following steps:

1. Define a property corresponding to the level of familiarization of the user. The value of this property might be inferred (for example, from the score in a diagnostic test) or declared by the user herself and

2. Create a condition to guide the learner to one of the alternative learning paths.

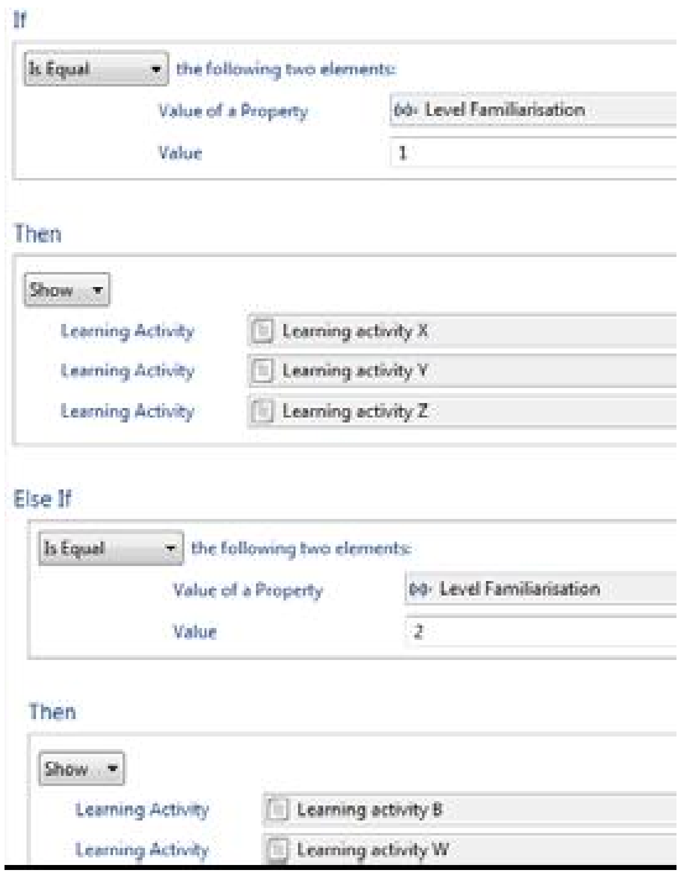


Figure 6 A simple adaptation rule using the IMS-LD ReCourse Editor

Figure 6 depicts  implementation of this condition using an IMS-LD editor. The figure would be very similar using any IMS-LD editor; the choice of the tool doesn't affect the implementation complexity.

The corresponding code snippet that realizes the adaptation rule in an IMS-LD runtime environment is generated automatically by the editor and it is shown in the box below. Again, the code remains the same irrespectively of the IMS-LD editor used.

```
<imsld:conditions>
   <imsld:if>
   <imsld:is>
     <imsld:property-ref ref= “levelfamiliarization" />
     <imsld:property-value>1</imsld:propertyvalue>
   </imsld:is>
 </imsld:if>
  <imsld:then>
     <imsld:show>
        <imsld:learning-activity-ref ref="learningactivity-X" />
        <imsld:learning-activity-ref ref="learningactivity-Y" />
        <imsld:learning-activity-ref ref="learningactivity-Z" />
    </imsld:show>
</imsld:then>
<imsld:else>
  <imsld:if>
    <imsld:is>
        <imsld:property-ref ref="levelfamiliarization"/>
        <imsld:property-value>2</imsld:propertyvalue>
    </imsld:is>
  </imsld:if>
<imsld:then>
<imsld:show>
```

```
      <imsld:learning-activity-ref ref="learningactivity-B" />
      <imsld:learning-activity-ref ref="learningactivity-W" />
   </imsld:show>
</imsld:then>
</imsld:else>
</imsld:conditions>
```

The developer of the adaptive courseware doesn't need to write any XML or other code to create an adaptive Unit of Learning (UoL), another affordance of the IMS-LD specification. The simple example above does not include sophisticated adaptation rules; changing it to contain adaptation strategies like the ones mentioned in Section 2 is straightforward. Consequently, the research on adaptive learning tools was initially motivated by the following: why do the non-technical instructional designers seem to find the process cumbersome? In Halm and Towle (2005) it is mentioned that although creating one simple adaptive strategy might be an easy task, combining different adaptive strategies that may overlap in a learning activity might be a much more demanding task. Taking into account the support levels of the adaptation types already mentioned, one may conclude that there are three levels of difficulty in designing and implementing adaptive, IMS-LD compliant Units of Learning:

- Level 1: one adaptation strategy
- Level 2: overlapping adaptation strategies that are fully supported by the specification
- Level 3: overlapping adaptation strategies not (all of them) fully supported by the specification.

This identification of difficulty levels provided a reference framework that was used in my preliminary research which is described in Chapter 4.

# Chapter 3. Theoretical and Methodological Frameworks

## 3.1 Theoretical frameworks

### 3.1.1. Shulman's model of Pedagogical Reasoning and Action

According to Shulman (1986; 1987) the teacher's knowledge base pertains to knowledge about the content to be taught, pedagogy, curriculum, learners' characteristics and educational contexts, educational purposes and values along with their philosophical and historical grounds, as well as, Pedagogical Content Knowledge. The latter represents "the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organised, represented and adapted to the diverse interests and abilities students and presented for instruction. PCK is the category most likely to distinguish the understanding of the content specialist to that of the pedagogue" (Shulman, 1987, p. 8).

Many educational researchers have been influenced by Schulman's view about Pedagogical Content Knowledge which is captured in his writings (Schulman, 1986, p.9-10) as follows:

> "Within the category of pedagogical content knowledge I include […] in a word, the ways of representing and formulating the subject that make it comprehensible to others. Since there are no single most powerful forms of representation [emphasis added], the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons."

Schulman's model of Pedagogical Reasoning and Action consists of:

- Comprehension, which relates to teachers' critical views and understandings about the subject matter structures and the educational purposes of teaching it. For example teachers understand how an idea relates to other ideas within the same subject matter area. Also, it entails comprehension of purposes.

- Transformation, which contains the following sub-phases:

    - o Preparation and critical interpretation of the given learning materials to be taught

    - o Representations in the forms of analogies, metaphors, images, stories, examples etc

    - o Selections of teaching methods and instructional strategies, that might include traditional approaches like seatwork as well as forms of more innovative approaches, like co-operative learning

    - o Adaptation and tailoring to student characteristics, like preconceptions, alternative conceptions, motivations, difficulties etc. It is here that ICT can provide a substantial addition: the individual student, personalized dimension to adaptation.

- Instruction, which includes various aspects of teaching like: questioning, interactions and grouping, learner control etc.

- Evaluation of performance, in the level of the individual student as well as in the class level. This involves checking for student understanding during interactive teaching, testing student understanding at the end of the lesson, evaluation one's performance and adjusting for experience. Again technology-enhanced adaptive instruction allows for personalized performance evaluation, for example through e-portfolios.

- Reflection through critical analysis of the teacher's and the students' performance

- New comprehensions, that is, consolidation of new understandings from the teaching experience in conjunction with parameters like: the subject matter, the students and possibly, the learning goals.

With regard to mathematical teaching Schulman's model has received some criticism from educational researchers in the field. For example, Meredith (1995) argues that "pedagogical reasoning, which leads to the transformation of subject knowledge, seems to be concerned primarily with the transmission of content. In mathematics this means little opportunity to present the subject as a process or 'science of patterns'.” However, Kirschner et al. (2006) suggest that the guidance level of the learner which is implied in Shulman’s views on PCK is required even in approaches distant from the transmission model (such as constructivist, experiential, problem-based and inquiry based teaching).

The approach adopted in this thesis, which is discussed in detail in chapters 5 and 6, results in learning designs that mostly embrace approaches distant from the plain “provision and consumption of content” and cater to realistic mathematics education through constructivist learning. The adaptive e-learning strategy which was incorporated in the design of the e-courses is driven by the inherent difficulties of the subject matter and provides suitable resources and feedback to overcome those difficulties while taking into account the students’ characteristics. The key observation of Schulman that links his PCK theory with adaptive instruction is that “there are no single most powerful forms of representation”, which implies the need for tailored instructional approaches. There is no limit to a teacher’s understanding of individual student learning aptitudes, needs and prior achievements. However the tutor’s chance to use this understanding in order to apply personalized instruction in a traditional class setting is severely restricted by practical and organizational barriers. So, although “there is no best instructional practice and the teacher is equipped with alternative forms of representation”, she is in practice restricted to a single one at a time, at best addressed to an idealized average student. The question then becomes: how can we feed the teacher’s PCK and her personal student understanding to a technology-enhanced environment that would be capable to distinguish specific student learning characteristics and provide to each a personalized learning path?

### 3.1.2 Simon’s Mathematical Teaching Cycle

Simon (1995) in his Mathematical Teaching Cycle describes the process by which a “teacher can make decisions in conjunction with the content, design, and sequence of mathematical tasks”. In short, this cycle consists of the following broad parts (Rider, 2004):

(1) Assessment of student’s prior knowledge and aptitudes.

(2) Identification of learning goals, of mathematical concepts and skills to be learnt as well as hypotheses about a path on which students might move in order to achieve these goals (Hypothetical Learning Trajectory).

(3) Planning and design of appropriate learning activities and enactment (i.e. teaching).

(4) Iteration of the process after reassessing students' understanding, if needed.

Towards specific learning goals identification, the teacher's knowledge of mathematics in tandem with her hypotheses about the students' mathematical knowledge, contribute decisively. Further, *"the learning goals, the teacher's knowledge of mathematical activities and representations, his knowledge of students' learning of particular content, as well as the teacher's conceptions of learning and teaching (both within mathematics and in general) contribute to the development of learning activities and a hypothetical learning process"*.

The term "Hypothetical Learning Trajectory" illustrates the idea that, prior to classroom instruction, the teacher predicts the path by which learning might proceed and accordingly, she develops a plan for the classroom activity. It provides a rationale for selecting a specific learning design and consists of three components: the learning goals, the learning activities and their representations, and the hypothetical learning process (Simon, 1995).

Figure 7 portrays that cycles of modifications of the Hypothetical Learning Trajectory occur on behalf of the teacher as she interacts with the students, observes them and assess their thinking, on the basis that the anticipated learning trajectory might be different form the actual one.

Figure 8 depicts the following relationships (Simon, 1995):

- The teacher's learning goals are influenced on her knowledge of mathematics and her hypotheses of students' knowledge.
- The teacher's plan for learning activities is influenced again by her knowledge of mathematics, mathematical activities and their representation, her hypotheses of students' knowledge and theories about mathematics learning and teaching.

- The teacher's hypothesis of process of learning is influenced again by her knowledge of mathematics, theories about mathematics learning and teaching and knowledge of student learning of particular content.
- The assessment of students' knowledge informs the domains of teacher knowledge

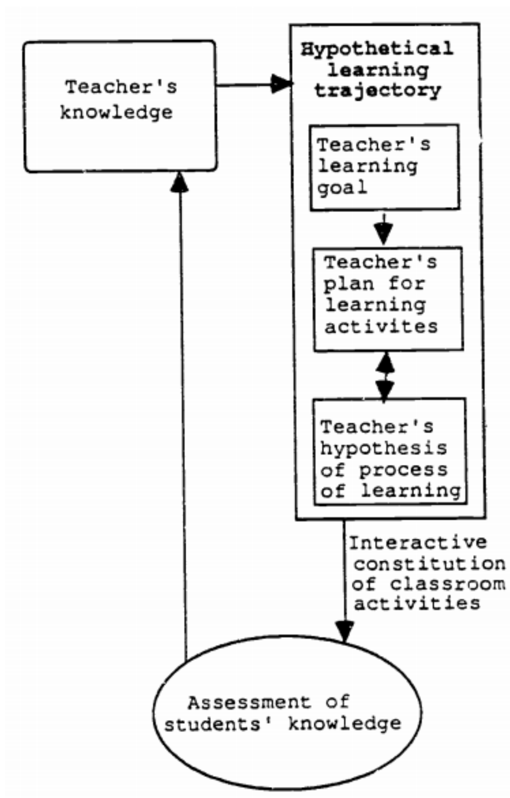


Figure 7 The Mathematics Teaching Cycle [figure taken from (Simon, 1995)]

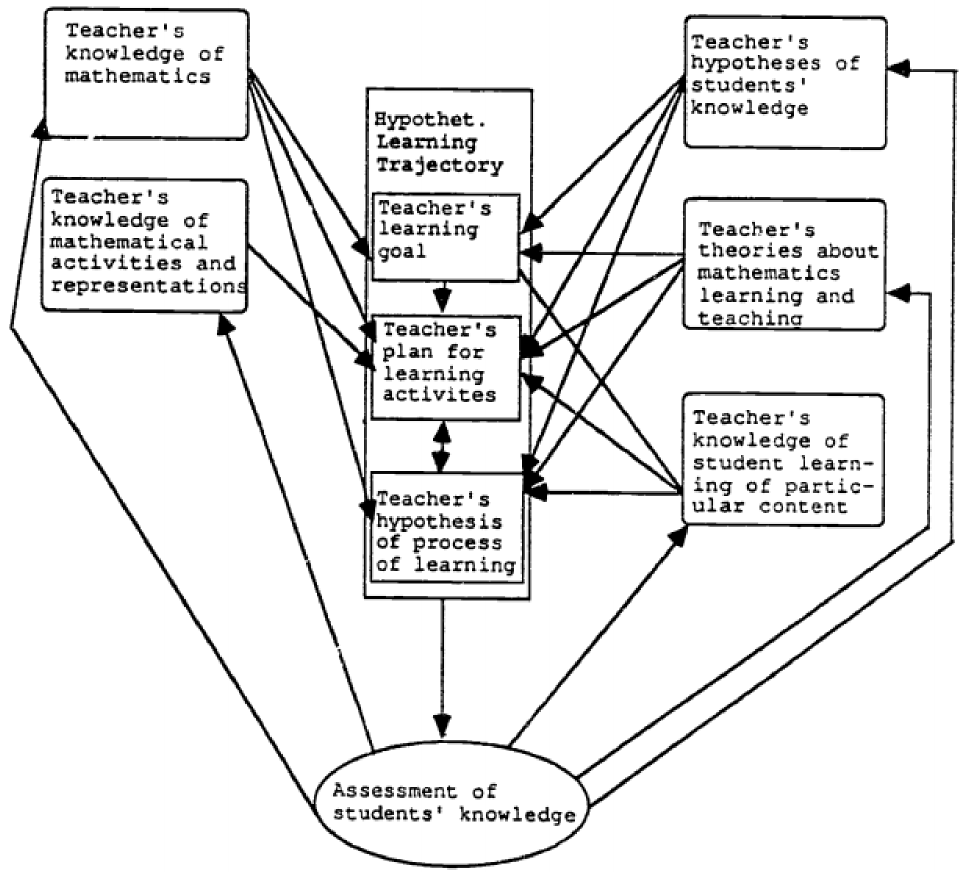


**Figure 8 Relationships between the assessment of students' knowledge, the domains of teacher knowledge and the hypothetical learning trajectory (Simon, 1995)**

According to Gravemeijer & van Eerde (2009), Simon, through the process illustrated in figure 7, a solution can be provided to the question "how to reconcile the constructivist stance that students construct their own knowledge with the obligation of formal education to strive for pre-given learning goals?" (p. 511). In Gravemeijer & Cobb (2006), Simon's work is examined from a Design Based Research perspective aiming at "creating innovative learning ecologies in order to develop local instruction theories on the one hand, and to study the forms of learning that those learning ecologies are intended to support on the other hand". This research concerns the area of realistic mathematics education within the domain of early, descriptive statistics. Riber (2004) has built upon Simon's theory in her dissertation in order to guide the practices of teaching mathematics that exploit multiple representations (symbolic, graphical, and tabular representations) about the concept of function.

### 3.1.3 Relevant examples

The purpose of this section is to provide practical examples related to the frameworks and models mentioned above. In parallel, the purpose of this section is it to clarify why I decided to exploit them for the purposes of my research.

**Shulman's model of pedagogical reasoning and action**

Usually, the papers that discuss about Shulman's model focus on the transformation of content. For the scope of this thesis, this section presents an example that illustrates how a teacher, without the use of technology, adapts his teaching practices in order to fine-tune his teaching with the profile and the needs of his students. In particular, the example below (Budak, 2013) presents a case of adaptive instruction within the English as a second language context and exemplifies how teaching pertains to decision making on behalf of the teacher in the events of dilemmas.

In this example, Rose teaches English grammar to students in grades 6-8. After observing similar grammar errors in her students' writings continuously, she decides to change her teaching practice. She realises that practising grammar only during the teaching sessions is not adequate, her students need extra help. While she continues on teaching at the moment of students writing grammar, she additionally introduces a series of mini lessons. These mini-lessons involve teaching grammar in isolation by explicitly addressing specific grammar features and discuss about them in a more direct way in order to make students understand them clearly.

The adaptive eLearning strategy proposed in this thesis also focuses on students' common errors and provides extra help to those that need it, similar to what Rose does with her students.

**Simon's Mathematics Teaching Cycle**

This section focuses on the concept of the Hypothetical Learning Trajectory. The figures below are taken from (Mousley, Sullivan & Zevenbergen, 2004) and illustrate the concepts of a) a hypothetical learning trajectory, b) actual learning trajectories, c) differentiated learning trajectories and d) alternative trajectories, respectively.

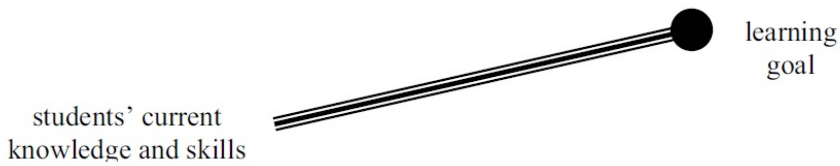


Figure 9 Hypothetical learning trajectory [figure taken from (Mousley, Sullivan & Zevenbergen, 2004)]

The hypothetical trajectory is the teacher's prediction on the path in which students might move to achieve the learning goals, based on their current knowledge and skills.

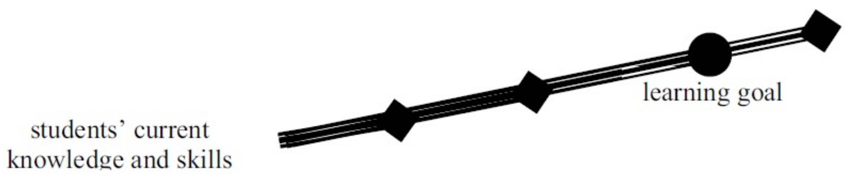


Figure 10 Actual learning trajectories [figure taken from (Mousley, Sullivan & Zevenbergen, 2004)]

In the figure above, the rhombus depicts the student's actual achievement. Actual learning trajectories are likely to take the shape depicted in the figure , since some students are more successful than others in reaching the learning goals. So, how can the teachers modify her planning or her behaviour when some students don't achieve the learning goals?

A solution depicted in the figure below would be to categorise students in 'ability groups' and assign different learning goals for each group. The literature suggests that such grouping in primary and secondary education has negative effects, for example, self-fulfilling prophesy.

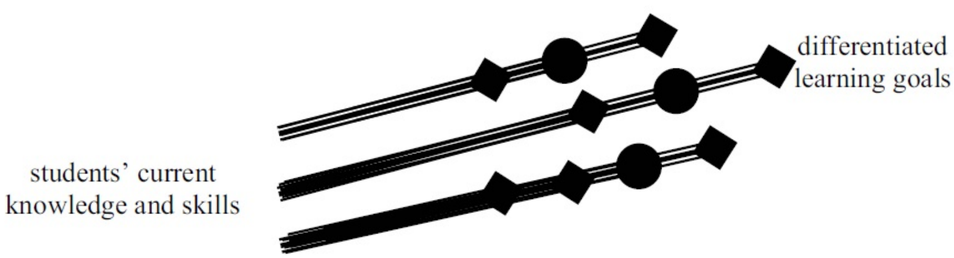


Figure 11 Differentiated learning trajectories [figure taken from (Mousley, Sullivan & Zevenbergen, 2004)]

Teachers realise that their student have sufficiently divergent needs and that a learning task may not be appropriate for all of them (Mousley, Sullivan & Zevenbergen, 2004). Forms of pedagogy that may help teachers to adapt tasks to the needs of the range of individual students in their classes are needed (ibid). This thesis suggests that teachers could move part of their effort from classroom implementation in planning how to cope with this issue through adaptive eLearning. Adaptive eLearning has the advantage that students need not to be aware of how they are categorised. Also, it may save effort on behalf of the teacher since the adaptive e-course is reusable (e.g.it may be used more than once), provided that user-friendly tools for the design of adaptive e-courses exist and that teachers are properly trained.

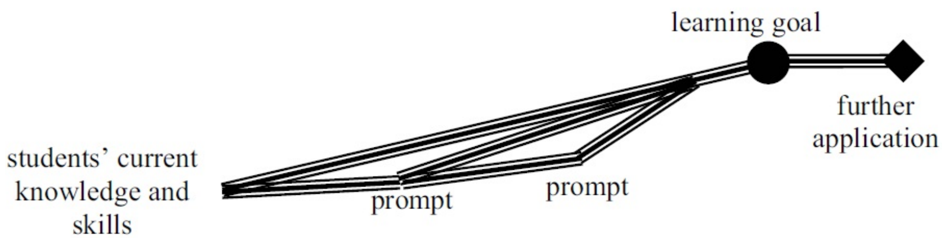


**Figure 12 Alternative trajectories [figure taken from (Mousley, Sullivan & Zevenbergen, 2004)]**

The figure above illustrates how all students can reach the learning goals. In a real classroom setting the teacher makes 'remedial' actions, in the form of 'prompt' activities that act as stepping stones to the trajectory that leads to the completion of learning goals, in case the student deviates from the trajectory. This strategy that imitates what a teacher actually does during classroom practice can also be realised through the affordances of adaptive eLearning.

## 3.2 Methodological frameworks

### 3.2.2 Design-oriented approaches

**Design Science: focus and difficulties**

Various disciplines, such as architecture and acoustics, aeronautics and engineering, medicine, computer science and artificial intelligence, education and learning design are included amongst design sciences (Collins et al., 2004). The foundations of design research belong to Simon (1969) who made the distinction between analytic and design science, or, otherwise put, the science of the artificial. Examples of disciplines that belong in the field of analytic sciences are physics, biology, and anthropology, which aim to understand how phenomena can be explained. Analytic (or natural) science “is concerned with what is”, whereas design science “asks what ought to be” (Mor & Winters, 2007, p. 62) or “determines how designed artifacts (airplanes, robots, concert halls etc) behave under different conditions” (Collins et al, 2004, p . 17). In auditoriums and concert halls researchers examine how different designs affect reflection, refraction, diffraction and other dependent variables. Similarly, a design science of education examines “how different learning-environment designs affect dependent variables in teaching and learning” (Collins et al, 2004). The intent of an educational design research endeavor is the production of new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic (as opposed to laboratory) settings (Barab and Squire, 2004; Van den Akker , 2006).

Effective design research aims at refining both practice and theory (Collins et al., 2004). However, design experiments are not carried out in laboratories but in naturalistic settings and actual learning environments, such as classrooms, where there exist variables which cannot be controlled. Thus, the researchers must take may decisions during the design process in order to balance objectives and limitations (Edelson, 2002). To cope with limitations that pertain to messy situations, design researchers try to optimize as much of the design as possible and then evaluate how it works (ibid, p. 19). Just like a consumer report the evaluation combines qualitative with qualitative data in order to approach the effectiveness of the design process and/or product holistically. Often, the researchers end up with large collections of data: video recordings of the interventions, outputs of students’ work, and others. Consequently, in conjunction with the collection and analysis of the data, data reduction problems, coupled with time constraints are possible. Additionally, design experiments tend to include numerous participants often with diverse profiles and, this might also entail a large amount of coordination work on behalf of the researchers. At the minimum, design research requires intensive and long-term collaboration between researchers and practitioners (Reeves, 2006). Factors like these make “design experiments difficult to carry out and the conclusions uncertain” (Collins et al, 2004). In addition to the messiness that characterizes the naturalistic settings, the process of the design itself is quite complex due to its open-ended nature and its relationship with creativity. Consequently, it is difficult for researchers to characterize and explain it (Edelson, 2002).

**The nature of design research**

Design research seeks to integrate the development of design solutions to practical problems in learning environments aiming at the identification of reusable design principles (Reeves, 2006). To this end, design experiments bear both a design focus, as well as, a focus on the assessment of critical design elements. The design team needs to make decisions about (a) the design process, (b) the needs and opportunities addressed by the design and (c) the form(s) that the ensuing design will take (Edelson, 2002). Design experiments are contextualized, but with an emphasis on generalizing to guide the design process. Ethnographical or other qualitative methods can provide valuable insight at how a design plays out in practice, whereas quantitative methods can be used in later research stages where large-scale studies are held for the estimation of the effects of independent variables on the dependent variables (Collins et al., 2004). Guidelines for carrying out design research suggested by Collins et al. (2004) involve: a) the implementation of a design (identify critical elements and their interplay, characterize how each is addressed), b) the modification of a design (modify the design if needed and start a new phase, characterize the critical elements of each phase, justify the reasons for making the modifications), c) multiple levels of analyzing the design (cognitive, resources, group or classroom, school or institution), d) measuring dependent variables (climate variables, learning variables, system variables), e) measuring independent variables (setting, learners, support, professional development, implementation path), f) reporting on research goals and intervention settings (description of each phase, outcomes, lessons learned, documentation) and g) characterizing dependent variables.

In conjunction with the latter, Collins et al (2004) argue that the success of an innovative design cannot be estimated in terms of how much students have learnt based on some criterion measure. A holistic evaluation addresses questions related, for example, to the sustainability of the design, whether the emphasis is on reasoning as opposed to rote learning, what is the impact on students' attitudes, etc. Hence, it is necessary to use a variety of evaluation techniques, like pretests and posttests, survey and interviews, classroom observations. Consequently, mixed methods are essential for design-research (Collins et al., 2004).

**Design research from various perspectives**

In the book "Educational design research" (Van den Akker et al, 2006) design research is viewed from three distinctively different perspectives: a) from a Learning Design perspective, b) from a curriculum perspective and c) from a technology perspective. This section summarizes the discussion that revolves around these perspectives.

<u>Design research from a Learning Design perspective</u>

This type of research seeks to develop theories about both the process of learning and the means that are designed to support that learning (Gravemeijer & Cobb, 2006). The approach adopted in this thesis combines these two.

From a design perspective, usually the goal of the preliminary research is to formulate a local instruction theory which, at later stages, can be elaborated and refined. From a research perspective, it is crucial to clarify its theoretical intent. This may include: clarifying the intended instructional end points (or learning goals) and the instructional starting points and the local instruction theory that the researchers have to develop. The latter encompasses both provisional instructional activities and a conjectured learning process, similar to Simon's Hypothetical Learning Trajectory, which is the case in this research Also, it may include the elaboration on the theoretical intent of the design experiment (Gravemeijer & Cobb, 2006),

The first step towards the preparation for a classroom design experiment in mathematics is the clarification of the mathematical learning goals (ibid). Towards this end, the researchers, in their effort to try to find better ways to achieve the given goals, might consider not taking the curriculum as a given. Instead, they need to scrutinize the most relevant or useful goals from a disciplinary point of view. Consequently, the design agenda might be interventionist in character. For the scope of this research, the identification of learning goals was driven by the inherent difficulties of the subject matter.

With regards to the meaning of a conjectured local instruction theory, Gravemeijer & Cobb, (2006) argue that it consists of conjectures related to the possible learning process and the means of supporting it. Interestingly, Gravemeijer & Cobb continue their reasoning by assigning to the research team the responsibility of anticipating "how students' thinking and understanding might evolve when the planned instructional activities are used in the classroom". In Simon's Mathematics Teaching Cycle, this was the teacher's responsibility. In the approach adopted in this thesis, there is a shared responsibility between the researcher and the teacher. The similarity among Shulman (1994), Gravemeijer & Cobb (2006) and the author of this thesis is that they all agree on the limited contribution of the research literature in identifying the hypothetical learning trajectory(ies). The difference is that Shulman pinpoints to the teacher, Gravemeijer & Cobb pinpoints to the research team and the author of this thesis pinpoints to researcher-teacher dyad to compensate for the fact that the research literature might provide only limited guidance.

Design research should ensure that the "clarification of the problems facing teachers and students, and ideally, the creation and adoption of solutions in tandem with the clarification of robust design models and principles" will be made in collaboration between the researcher and the teacher, so that the ensuing progress reflects teacher's practice (Reeves, 2006).

Design research from a technology perspective

The effectiveness of the educational technology field has been doubted, as has the efficacy of educational research in general[13]. During the last decades, the educational technology research agenda has been accused as being pseudoscientific and socially irresponsible (Reeves, 2006). To compensate for this, design research has been proposed as an alternative model for inquiry aiming in the enhancement of teaching and learning through technology (ibid).

A controversial issue within the educational research and development community pertains to the value and feasibility of Randomized Controlled Trials (RCTs), as an approach capable of yielding progress in education. Slavin (2002), one of the most prominent proponents of RCTs,

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[13] Efficacy trials (explanatory trials) determine whether an intervention produces the expected result under ideal circumstances. Effectiveness trials (pragmatic trials) measure the degree of beneficial effect under "real world" settings. [Source: Gartlehner G, Hansen RA, Nissman D, et al. Criteria for Distinguishing Effectiveness From Efficacy Trials in Systematic Reviews. Rockville (MD): Agency for Healthcare Research and Quality (US); 2006 Apr. (Technical Reviews, No. 12.) 1, Introduction. Available from: http://www.ncbi.nlm.nih.gov/books/NBK44024/]

asserted that if the educational research community could learn from the lessons of medical practice (where the application of RCTs is the norm), then similar observable progress could be achieved in the field of education. On the contrary, other researchers, like Olson (2004) and Chatterji (2004), expressed their reservations about the suitability of RCTs in the field of education, and, instead of RCTs, they recommended extended-term mixed method designs, as well as, a "decision-oriented" over a "conclusion-oriented" approach (Reeves, 2006).

In practice, reviewing the field of DBR was confusing, in that, it was not distinguishable, why a best practice is actually a best practice. For example, the development research of Herrington (Herrington, 1997; Herrington & Oliver, 1999) is considered by Reeves (2006) an exemplar of design-based research. The research plan of this endeavor was the following (Reeves, 2006): at first, Herrington developed a model of the critical factors of situated learning by working with teacher educators, and secondly, she and her team embedded these factors in the design of a multimedia learning environment. Next, the model and the technological products were tested in multiple contexts, including pre-service teacher education and K-12 schools. In doing that, she employed a range of strategies, like video analysis of the dialogue between pairs of students while they were engaged in multimedia learning. Although this research effort was important not only within the immediate context of its implementation, but also yielded generalizable design principles which can be applied in other contexts (Reeves, 2006), yet in terms of software engineering and development it seems that the typical watercycle model was followed , which is a classical, non-iterative and linear approach.

Design research from a curriculum perspective

It is difficult to define what a curriculum is, but certainly its purpose is to describe somehow what should be learnt and how – a plan for learning (McKenney, Nieveen & Van der Akker, 2006). The pillars of the curriculum are: society (respond to societal needs and/or trends), learner (identify learner characteristics that have a significant impact on the learning process) and knowledge (what should be learnt). With respect to knowledge, the by-product of design research is incorporated in design principles (heuristics, domain theories, lessons learnt). They can be described in the form suggested by van den Akker (1999, p .118):

"If you want to design intervention X [for purpose/function Y in context Z]; then you are best advised to give that intervention the characteristics C1, C2, …, Cm [substantive emphasis]; and do that via procedures P1, P2, …, Pn [procedural emphasis]; because of theoretical arguments T1, T2, …, Tp; and empirical arguments E1, E2, … Eq."

The secondary output is the societal contribution of design research that usually yields to curricular products or programs. Examples include teacher guides and software for students. The tertiary output is about the teachers' professional development since there is a strong linkage between the development of the curriculum and teachers' development. A recent example of how DBR can help in the curriculum design domain comes from the University of Helsinki. In their article, Luukkainen, Vihavainen and Vikberg (2012) discuss about three consecutive years (fall 2009-Spring 2012) of DBR to reform a software engineering curriculum. The problem of the paper is that "institutions giving education in software engineering end up teaching the subject using outdated practices with technologies no longer in use" (p. 209). Consequently, the goals of DBR was to reform the curriculum so that students would have strong up-to- date theoretical and practical skills in software engineering but not to the expense of any of the existing theoretical aspects.

Since, in this case, the design artefact was an intervention into current practices, the process of developing the artefact begun with an initial problem analysis. The development of the artefact continued in iterative cycles and the evaluation was undertaken repeatedly at the beginning of each iteration as well as during iterations. This led to an improved artefact but also, at the same time, to enhanced understanding of the process that led to the improvement.

### 3.2.1 Design-Based Research

Design-Based Research (DBR) is a modern methodology included in the design research field and originating from learning sciences. As with design research, DBR also aims to bridge theoretical research and educational practice (Design-based Research Collective, 2003). But it is my understanding that DBR should be interventionist, in that is does not only focus on the design and testing of artefacts, such as activity structures, scaffolds etc, but also on the relationships among theory, the designed artefacts and practice in naturalistic settings (Design-based Research Collective, 2003). The basic steps are (Peer Group, 2006a):

- Definition of a meaningful problem
- Collaboration with practitioners
- Integration of robust theory about the teaching-learning process
- Generation of research questions (through literature review, needs analysis etc)
- Design of the educational intervention
- Development, implementation and revision of the design intervention
- Evaluation of its impact
- Iteration of the process
- Report of the results

In a more broad sense, the phases of design-based research suggested by Reeves and his colleagues (Reeves, 2006; Herrington et al., 2007) can be summarised as follows:

- PHASE 1 is about analysis of practical problems by researchers and practitioners in collaboration
- PHASE 2 is about development of solutions informed by existing design principles and technological innovations.
- PHASE 3 is about iterative cycles of testing and refinement of solutions in practice
- PHASE 4 is about reflection to produce “design principles” and enhance solution implementation.

In DBR, the design of educational intervention starts with the definition of a meaningful problem for the practitioners and requires their collaboration in order to produce robust results (Edelson, 2002; Peer Group, 2006b). DBR has come to provide an alternative to strictly observational research methods, like the traditional empirical research, in which the experiments are designed to test hypotheses with the aim of specifying new ones. It was developed to address issues which are central in learning, like the need to "go beyond narrow measures of learning" and "derive research findings from formative evaluation" (Collins et al, 2004). In addition, DBR is complementary to predictive research, thus it is difficult to compare results across designs (ibid). This is depicted in the figure below.

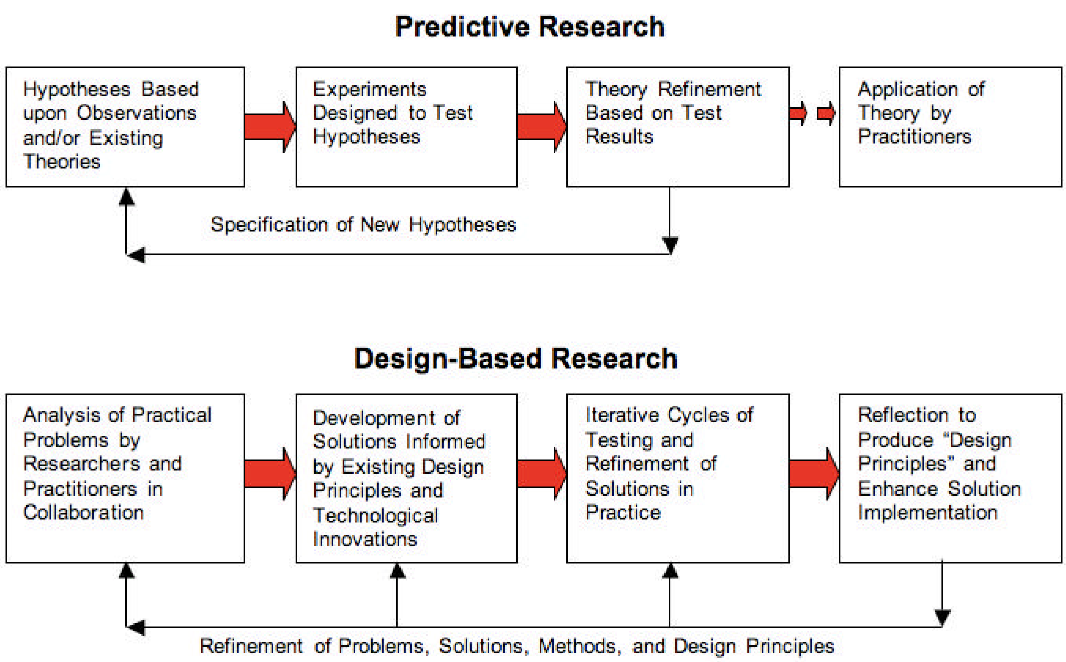


**Figure 13 Predictive research and design-based research in educational technology research [figure taken from (Reeves, 2006)]**

DBR is (Wang & Hannafin, 2005): pragmatic, grounded, interactive, iterative and flexible, integrative and contextual. "Pragmatic" refers to the idea that a) DBR deals with the interplay between theory and practice and b) the value of the former is appraised on the extent to which its principles and concepts inform the latter (Design-Based Research Collective, 2003; Wand & Hannafin, 2005). "Grounded" refers to the theory-driven nature of DBR. Researchers select a theory about learning and instruction in a preliminary stage of DBR and, subsequently, they try to revise and/or refine the theory. In addition, the iterative nature of DBR is highlighted by many researchers (see the steps proposed by Peer Group above and in the process depicted in figure

12). The DBR process is interactive and flexible due to the fact that it involves messy real-world settings that entail close and continuous (as possible) researcher-teacher collaboration, as well as, the engagement of other key stakeholders. Although the distinction among designers, researchers, and participants might be blurred (Bannan- Ritland, 2003), the role of the researchers is to "manage the design process, cultivate the relationship with practitioners, and most importantly, develop their understanding of the research context" (Cobb et al., 2003; Wang & Hannafin, 2005, p.9). Also, the concept of flexibility is related to the fact that the theoretical framework that guides the DBR process may be extended and/or modified and, in some cases, a new framework may emerge (Wang & Hannafin, 2005). Another case is that the initial design plans may be insufficient, so modifications are anticipated and implemented when needed (Edelson, 2002; Wang & Hannafin, 2005). "Integrative" refers to the exploitation of qualitative as well as quantitative methods in different stages of intervention. DBR does not impose or exclude any particular methodology but, instead, it draws conclusions from a variety of methods: surveys, interviews, case studies, comparative analysis etc. (Wand & Hannafin, 2005). In fact, the triangulation of conclusions fostered by the combination of qualitative and quantitative methodologies may increase the quality of the research endeavour, in terms of enhanced external validity, objectivity etc. (ibid). Finally, DBR is "contextual" in the sense that the research process, the research outcomes, and any deviations from the initial research plan need to be well-documented so that interested researchers can trace the contextual factors or situations that led to certain effects (Wang & Hannafin, 2005; Baumgartner & Bell, 2002).

The ensuing design principles may be generic or content specific (Bell et al., 2004). For example, in the context of the "Computer as Learning Partner" curriculum (Linn & Hsi, 2000), a series of design studies were conducted, emphasising science learning and instruction. Four generic principles were generated: 1) make science accessible, 2) make student thinking visible, 3) foster students' mutual learning, 4) promote lifelong and autonomy learning

In conclusion, I selected this methodology because its features are very aligned with the characteristics of this research:

- working on real-world problems in naturalistic settings

- iteratively searching for a solution to that problems
- practitioners are co-designers
- mixed method are used for the evaluation of the design process and its outcomes

### 3.2.3 Grounded Theory

Grounded Theory (GT) is a qualitative methodology originating in sociology (Glaser and Strauss, 1967; Strauss and Corbin, 1990) and exploited in a range of diverse disciplines, like nursing and health (Sandelowski, 1995), educational studies and educational technology (Mavroudi & Hadzilacos, 2013), organisational studies (Parry, 1998), information systems and software engineering (Alan, 2003; Halaweh, 2012; Halaweh et al., 2011; Coleman & O'Connor, 2007) and many others. There exist three fundamental differentiating components in the GT process: a) theoretical sampling, b) coding, c) constant comparative analysis. Theoretical Sampling is the purposive selection of those informants who are most likely to provide early information related to the phenomenon studied (Goulding, 2005) or are likely to maximize the potential of discovering as many conditions, dimensions, actions/interactions or consequences of the phenomenon studies as possible (Strauss & Corbin, 1998). Coding is a key process beginning at the early stages of the GT process, in which the researcher needs to pay attention to theoretical sensitivity. Simply put, the researcher needs to be able to identify data that is significant for the phenomenon studied and to assign meaning to it. The coding process is done in three steps:

- Step 1: Open coding is "the process of breaking down, examining, comparing, conceptualizing and categorizing data" (Strauss and Corbin, 1990, p.61). This can be accomplished either line by line or by focusing on meaningful ideas in phrases or paragraphs. Each code represents a word or small group of words encompassing a meaningful idea. In open coding, codes are compared with others in terms of similarities and diversities in order to assign to them, when they are conceptually similar, the same label (Halaweh, 2012). This principle for analysing and abstracting the information is the constant comparison method (Goulding, 2005).
- Step 2: Axial coding pertains to reassembling the data broken down in Step 1, in order to identify interrelationships between codes, through a combination of inductive and deductive thinking.

- Step 3: Selective coding is the process of integrating and refining the theory, starting by identifying the central or core category of the phenomenon studied and link the other categories to it.  A rule of thumb is that the core category a) appears repeatedly in the data (Halaweh, 2012),  b) pulls together all the concepts in order to offer an explanation of the phenomenon (Goulding, 2005) and c)  is traceable back through the data (ibid)

### 3.2.4 Qualitative Comparative analysis

Qualitative Comparative Analysis (QCA) bridges qualitative and quantitative analysis, while providing powerful tools for the analysis of causal complexity (Ragin 1987; 1997). It is ideal for small-to-intermediate-N research designs (e.g. 5 to 50). Typically used in the field of social sciences, it is complementary to conventional quantitative analysis, in the sense that it doesn't only reveal correlational connections, but also set-theoretic connections and causality between variables (Ragin, 2002; Rihoux & Ragin, 2009). It examines necessity and sufficiency which are difficult to assess using conventional quantitative methods.

QCA is based on Boolean algebra, where a case is either in or out of a set, and it uses binary-coded data, with 1 indicating membership and 0 indicating non-membership. QCA using conventional, crisp sets is also known as csQCA. Boolean algebra provides the basis for qualitative comparison. There are two conditions or states: true (or present, coded as 1) and false (or absent, coded as 0). The typical Boolean-based comparative analysis addresses the presence/absence conditions under which a certain outcome is obtained (that is, is true). In order to use Boolean algebra for qualitative comparison, it is necessary to reconstruct a raw data matrix as a truth table. Truth tables have as many rows as there are logically possible combinations of values on the causal variables. If there are three binary independent variables, for example, the truth table will contain 23 = 8 rows, one for each logically possible combination of three presence/absence independent variables. The typical application of QCA results in a logical statement describing combinations of conditions that are sufficient for the outcome. The listed combinations may or may not be exhaustive, that is, they may not explain all instances of the outcome.

The truth table algorithm involves a two-step analytic procedure which makes use of the Quine-McCluskey algorithm. The first step consists of creating a truth table from the raw data, which primarily involves specifying the outcome and causal conditions to include in the analysis. The second step consists of preparing the truth table for analysis, by selecting both a frequency threshold and a consistency threshold.

The use of fuzzy sets in QCA, which enables multi-value QCA (MVQCA) is an extension to the binary QCA (i.e. csQCA) in that csQCA only deals with dichotomous variables, 0 and 1 (Cronqvist & Berg-Schlosser, 2009). In practical terms, the MVQCA permits the values of a five-step ordinal scale, like a 5-point Likert scale, as input data (Cronqvist, 2003).

### 3.2.5 Screen recording and video analysis

Audio and video recordings assist researchers in capturing verbal and nonverbal interactions (Stauffacher & DeHart, 2005). Screen capturing recording combines the benefits of both audio and video recording while reducing reactivity to the recording devices of participants observed in their natural settings (Pellegrini, 2004), as opposed to laboratory settings. Audiovisual observational recordings provide the opportunity of creating a video for subsequent coding, as well as, a verbal transcript, which contributes in placing the video in context. Schulz-Zander et al. (2008) argue that "a combined use of videotaping and audio-recording can be useful since multiple types of data enable the data to be cross-checked and thereby increase confidence in the conclusions drawn" (p. 371). Yet, they continue on arguing that a more elaborate triangulation approach would enable the interpretation of the data acquired through observational methods with other quantitative data (acquired through questionnaires or tests etc) or qualitative data (acquired through interviews or brainstorming etc). Mixed methods could provoke more reliable and valid results.

The use of audiovisual observation methods is frequently mentioned in the recent research literature. Below, three examples of using audiovisual observation through screen recording (combined with audio recording), are discussed in brief.

- Example 1: a research study on computer-mediated interaction focusing on how people interact with computers to accomplish everyday collaborative tasks (Tang et al., 2006).

The research purpose was to understand how teams make use of their computers to coordinate their efforts in order to identify new design opportunities for computer supported collaborative work. The researchers concluded that the method is unobtrusive but invasive and raised various privacy issues. They used the Camtasia Studio screen recording software™ (http://www.techsmith.com/camtasia.html ).

- Example 2: a research study to investigate the interplay between students' computer competencies and acquisition of knowledge conducted by Wecker et al. (2007). Schulz-Zander et al. (2008) refer to this effort as "a technical state-of-the-art observational approach" (p. 371) because the screen recording process enabled the interpretation of what was seen by the computer uses on their screens in tandem with the information acquired by commenting on their activities. In this study, the Videograph software™ (http://www.dervideograph.de/enhtmStart.html ) was used.

  Example 3: a research study focusing on collaborative inquiry web-based activities as a means to acquire Web literacy skills in the context of primary education. All students worked in pairs and all sessions were captured with the Camtasia Studio screen recording software™ which also recorded the student pairs conversations (Kuiper et al., 2010). The study aimed at identifying contextual factors affecting both the development of Web literacy skills and content knowledge building on behalf of the students.

## 3.3 Research validity and reliability

The aim of the section is to discuss some basic considerations about two properties of any research method or process: validity and reliability. They are defined here and in Chapter 6 they are discussed in the context of this thesis, that is, I answer how they apply in the context of my research.

### 1. Validity

For the scope of this thesis validity is a property that answers whether the researcher has actually measured what he intended to measure before in the beginning of his research. It is categorised to external validity and internal validity. The internal validity refers both to how well the study was run (research design, operational definitions used, how variables were measured, what was/wasn't

measured, etc.), and how confidently one can conclude that the change in the dependent variable was produced solely by the independent variable and not extraneous ones.
Some of the most well-known threats to internal validity are (Bergh et al. 2004; Brewer, 2000; Cook & Campbell, 1979) :

1.Self-selection effects, when participants can select their own treatments

2.Experimental mortality, when participants drop out of a study.

3.History, when some kind of event, which is not the treatment of research interest, occurred between the measurement periods

4.Maturation effects are especially important with children and youth, since they can arise when an observed effect might be due to the research subjects' changing biologically or psychologically over the study period and those changes are not attributed to the study setting

5.Regression toward the mean effects are especially likely when you study extreme groups. For example, students scoring at the bottom of a test typically improve their scores a least a little when they retake the test. Students with nearly perfect scores might miss an item the second time around. To avoid this threat randomly assign extreme groups to intervention conditions, including a control group.

6.Testing, just taking a pretest can sensitize people and many people improve their performance with practice. Also, "familiarity with a test can sometimes affect responses to subsequent administration of the test" (Bergh et al, 2004).

7. Instrumentation, when a measuring instrument is changed or when an observer or scorer changes over time.

Concerning external validity, it is the extent to which the results of a study can be generalized to other situations and to other people. It can be divided into population validity and ecological validity (Bracht & Glass, 1968). Population validity seeks to answer two main questions: a) How representative is the sample of the population? and b) How widely does the finding apply? Ecological validity is present to the degree that a result generalizes across settings.

2. **Reliability**

For the scope of this thesis reliability is a property that is concerned with the extent by which the research findings are repeatable and testable by other researchers. It aims to answer the question "If the study was to be conducted a second time, would it yield the same findings?". A formal definition is the following: "Reliability is the extent to which a test or a procedure produces similar results under constant conditions on all occasions" (Bell, 1987 pp. 50-51). It demonstrates that "the operations of a study –such as the data collection procedures- can be repeated with the same findings" (Yin, 1994, p. 144).

Common threats to reliability are (Gravetter & Forzano, 2011, p. 86):

- researcher (or observer) error; introducing simple human error when carrying out measurements
- environmental changes; changes in the environment from one measurement to another provided that these changes may have an impact on the measurements
- participant changes.

Methods to sustain or assess reliability include:

1. Successive measurements, which pertain to one of the following methods:

- test-retest reliability on separate days. For example, assuming the case of a pre-post test research design, where the same test is administered to the same persons, the correlation co-efficient between pre-test scores and post-test scores could be used. A strong correlation, would highlight consistency between the two tests, which indicates that the measurement procedure is reliable
- the parallel-forms method. It is used to assess the reliability of a measurement procedure when different or modified versions of it are used for the test and retest. It can be tested via a t-test, similarity of means and standard deviations and a high correlation coefficient.

2. Simultaneous measurements by more than one researcher, which may reduce experimenter or instrument bias. In this case, the inter-rater reliability should be mentioned since it indicates the degree of agreement between the researchers or the observers.

Another statistical measure that pertains to research instrument reliability is the Cronbach's alpha coefficient which measures reliability as internal consistency (Cronbach, 1951). Most likely, it is used in written or standardized tests (e.g., a survey).

**Sampling**

This papagraph discusses considerations about sample size and sampling procedures.

Sample size: the sample size has been (and still is) a controversial issue in each research strategy. Some scientists believe that "the more, the merrier", while others claim that both an excessively large sample size as well as a too small sample size can potentially lead to incorrect findings. The truth about the proper sample size is more complicated: its estimation is a complex matter that, in its simple case, it relates to a set of interweaved parameters such as the sampling strategy, the confidence interval [14], the confidence level [15], the response distribution and the population. Recently, online sample size calculators have been created that aim to simplify the process of the sample size determination by automatically performing all the complex underlying calculations. Examples include: http://www.surveysystem.com/sscalc.htm and http://www.raosoft.com/samplesize.html .

In the case of Randomised Control Trials (where the participants are randomly allocated either in the focus group or in the control group), the calculation of the recommended sample size is even more complicated, since it depends on: the significance level alpha (1-confidence level), power

[14] Confidence interval is the amount of error (represented in a percentage format) that the researcher or the statistician is willing to tolerate.

[15] Confidence level is the uncertainty (represented in a percentage format) that the researcher or the statistician is willing to tolerate. The most common value of the confidence level in research is 95%.

(1-beta)[16], percentage 'success' in control group and percentage 'success' in focus group. That is, the researcher needs to decide a priori the percentage 'success' in both groups, something that seems unorthodox. An online calculator for a RCT is available at: https://www.sealedenvelope.com/power/binary-superiority/ (prerequisite: the answer distribution in both groups approximates the normal distribution).

Sampling strategy: the sampling strategy is derived usually from the research design and the research methods, while taking into account research ethics. Two broad categories of sampling techniques exist:

- Probability sampling techniques, in which each member of the population has an equal probability of being selected since they are randomly selected. The most well -known are:

  a) simple random sampling, a process that consists of population definition, sample size selection, population listing, assignment of consecutive numbers to cases and use of random number tables or random number generators to select the sample.

  b) systematic random sampling, a process that differs from the simple random sampling in that after assigning consecutive numbers to cases, the sampling fraction (the sample size divided by the population size) is calculated. Then, the first case is selected after consulting random number tables or random number generators and the subsequent ones are selected taking into account the sampling fraction (for example, select one student in every 34 students).

  c) stratified random sampling, a process that consists of population definition, sample size selection, stratification parameter selection (for example, gender), population listing, assigning consecutive numbers to cases in each stratum, simple random sampling in each stratum.

- Non-probability sampling, in which the members of the population are chosen on the basis of personal judgment or convenience. This is not to say that this method is of no value. On the contrary, it can be used in studies that revolve around mixed research

[16] Alpha or significance level is the probability of making Type I errors (i.e. false positive); its most common value is 5%. Beta is the probability of making Type II errors (e.g. false negative); its most common value is 10%.

methods, qualitative research designs or, even, quantitative designs (for example, due to lack of access to the target population etc). The most commons are:

a) quota sampling, where the aim is to end up with a sample where the strata being studied are proportional to the population.

b) self-selection sampling, when the researcher allows cases to participate in the research on their own accord.

c) convenience sampling, in which the cases are selected on the basis of their convenient accessibility and proximity to the researcher or statistician.

d) snowball sampling is particularly appropriate when the target population is hidden and/or difficult-to-reach (such as drug addicts, individuals with AIDS/HIV etc).

e) purposive sampling, is also known as judgmental or selective sampling, since the selection of the cases relies on the subjective judgment of the researcher. Techniques that fall in this category include homogeneous sampling, deviant case sampling, expert sampling, typical case sampling and others.

# Chapter 4 Preliminary research & design

This chapter discusses preliminary research actions. The first part (section 4.2) of the preliminary research is motivated by the fact that an opportunity is being shadowed by a problem: adaptive learning can be managed effectively by the IMS-LD specification (the opportunity) which has been criticized as being too technical (the problem). The concepts of Learning Design and IMS-Learning Design have already been defined in section 2.12, as well as how the IMS-Learning Design can serve as the adaptation basis (section 2.13). As already discussed the IMS-LD models the adaptive behaviour of a Unit of Learning (like, an e-course), through a rule-based modelling approach. That is, the adaptation strategy on any IMS-LD compliant follows a deterministic model of “IF…THEN….ELSE” rules that can be regarded as a set of Finite State Machines (FSMs). Indeed, the IMS-LD specification has been frequently used for adaptive, web-based learning (see section 2.13), but it has been criticized for being too difficult for non-technical users (see for example Gómez et al (2009)). This restricts the development of IMS-LD compliant courseware to these sub-groups of stakeholders (researchers, teachers, instructional designers) that have a fairly good technical background. In order to confirm this hypotheses and realise where exactly lies the implementation difficulty, I designed and developed adaptive and IMS-LD compliant educational components. In particular: an adaptive e-course and adaptive educational components such as an educational recommender system and a set of integrated adaptive pathways/rules. I then demonstrated those components and the implementation logic behind them to a small group of novice instructional designers. They were interested in creating their own adaptive learning designs. These components were later evaluated by the small group, in order to confirm what the recent literature states: that the implementation logic is difficult for novice instructional designers and educators. Succinctly, the hypothesis was partially confirmed.

In Chapter 2, I also discussed about the learner model and potential adaptation parameters. The second part (sections 4.3 and 4.4) is motivated by what Randi & Corno (2005) mention: “most previous research-based knowledge about teaching and learner differences, hails from educational psychology traditions such as factor analysis and psychometrics, which are disconnected from what teachers actually do when they teach” (p. 48). To compensate for this issue, and taking into account that relevancy with teachers’ practices is important for my research, I conducted some preliminary research in order to set the grounds on which to build a strategy for adaptive learning that is relevant to teacher's practical experience. To this end, I conducted two surveys: the first one relates to the adaptation parameters that teachers use in their respective classrooms, regardless of the use of technology in their teaching. The second survey reveals that teachers could associate their adaptation practices better with a particular learning style model (originate from educational psychology), again regardless of the presence of technological means in the teaching-learning process. This particular model was incorporated in the design of a "teacher-friendly" tool for adaptive learning, which is discussed in detail in Chapter 7.

The third part of the preliminary research (part 4.5) discusses how I concluded that Computer Supported Collaborative Design (CSCD) would be an indispensable feature of an all-encompassing adaptive e-learning environment. That is, that the "teachers as co-designers of adaptive e-learning" concept is an important enabler for the "teacher as designer of adaptive e-learning" concept. This part of the preliminary research makes use of the Grounded Theory (see section 3.2.3). The CSCD principle is one of the conjectures that was incorporated in the design described in the Chapter 7. In particular, section 4.5 discusses a case study where novice instructional designers acted as designers for adaptive e-learning. This case study has implications for the creation of an user-centered environment that supports the authoring/creation of complex adaptive e-courses. I call these implications design conjectures (see Chapter 1) since they are mirrored in the design described in Chapter 7. These implications involve the Computer Supported Collaborative Design and the provision of design templates to the end users to help them reasoning and scaffold their design.

## 4.1 Adaptive learning scenario

I created an adaptive learning scenario and the corresponding adaptive e-course, that in terms of implementation difficulty, was in accordance with level 3 (see section 2.13). That is, I used this e-course as a complexity and implementation difficulty benchmark. The learning scenario was IMS-LD compliant and it consisted of five phases, each containing numerous learning tasks. The phases were the following:

1. Diagnostic evaluation concerning student prior knowledge

2. Presentation of the new knowledge

3. Test new knowledge

4. Synthesis of new knowledge and reflection

5. Knowledge application

The diagnostic quiz was implemented in the first phase and the educational recommender system in the third phase. The latter recommended to the student an assignment based on her performance in the previous phase, e,g phase 3. The initial hypothesis for the development of the educational recommender system was that no technical knowledge is required, since the needed adaptation work is form-based represented by the authoring tool used as a set of adaptation rules. An adaptation rule is depicted in figure 6a, section 2.13.

In this specific learning scenario, the learning process follows a deductive-inquisitory approach since it presents information to the students and then the students themselves produce complete examples of work as assignments. The learning scenario uses various categories of adaptation (adaptive learning flow/content, adaptive grouping, adaptive feedback and adaptive evaluation) that were needed in order to support the learning goals. The e-course incorporated two roles: the student and the tutor. Web2.0 tools (chat, forum and a wiki) were also incorporated to support collaboration and communication between the participating roles. The title of the adaptive learning design was "Learning Courselab" since its aim was to familiarise the student with the basic functionalities of an eLearning tool(namely, Courselab[17]). The learning activities were basically a set of "How-To's" presenting the key functionality of the tool. The assignment at the end of the e-course requests from the student to synthesize their knowledge and implement a showcase (i.e. a complex design task) using the authoring tool. The next section describes the learning flow of the adaptive e-course in more detail.

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[17] CourseLab is an authoring tool, http://courselab.com/

### 4.1.1 Learning flow of the adaptive course

First, the student logs in and selects this particular course from the list of available courses (i.e. courses in which he/she is enrolled).

Phase 1. Diagnostic test

The student answers Question 1 “Have you ever worked before with CourseLab?”.

If the student answers “YES”, then the system shows a list of the titles along with a short description for each “How-To”. The student ticks those he/she is not familiar with.

Phase 2. “How-to’s” & “Showcases”: presentations & tests

2.1. Presentation of “How-TOs”.

If the student answers “NO” to the question 1, then the system shows a list of all the “How-To”s.

If the student answers “YES” to the question 1, then the system shows only that “How-To” s that he/she has chosen to see in the previous step.

2.2. Test knowledge on the functionality of the tool

For each “How-To” a corresponding (multiple choice) question is presented. The system records student’s progress and measure his/her performance. The system gives adaptive feedback to the student, according to his/her performance and informs the tutor about it.

2.3. Reflection upon the test results. The tutor and the students discuss the test results in an online forum (the system launches the forum automatically).

Phase 3. Reflection

3.1. The system presents the showcases (the same to all students)

3.2. The system informs the students about the prerequisite “How-To”s for each Showcase

3.3. The system reminds the prior student performance in each the “How-To” to each student

3.4. The system suggests a specific showcase to each student (based on his prior performance)

3.5. The student and the tutor discuss about the suggested showcase in a dedicated chat room and they either agree with the system’s suggestion or they select another showcase.

3.6. The tutor performs the final selection concerning the showcase that will be assigned to each student

Phase 4. Application and synthesis of knowledge

4.1. The system provides the appropriate media sources to each student according to the showcase that he/she will implement (i.e. the media files needed)

4.2. The student downloads the files and then creates the showcase.

4.3. The student uploads the file that contains his/her work.

4.4. The students download and peer review (by assigning grades ranging from 1 to 5 stars) their work anonymously.

4.5. The system shows the results of the grading to everyone and also informs (sends via email) the tutor about them.

4.6. Each student writes a paragraph with the title of the showcase, it functional characteristics and its intended uses to a common wiki (The system automatically launches the wiki).

Below, the workflow diagram of the course is presented. For its design, the graphical conventions followed in the IMS Learning Design Best Practice and Implementation Guide (IMS GLC, 2003) were adopted.

At the beginning of the adaptive e-course, the students self-evaluate their prior knowledge (point 2.1 mentioned above). The figure below illustrates the flow of the adaptive e-course.

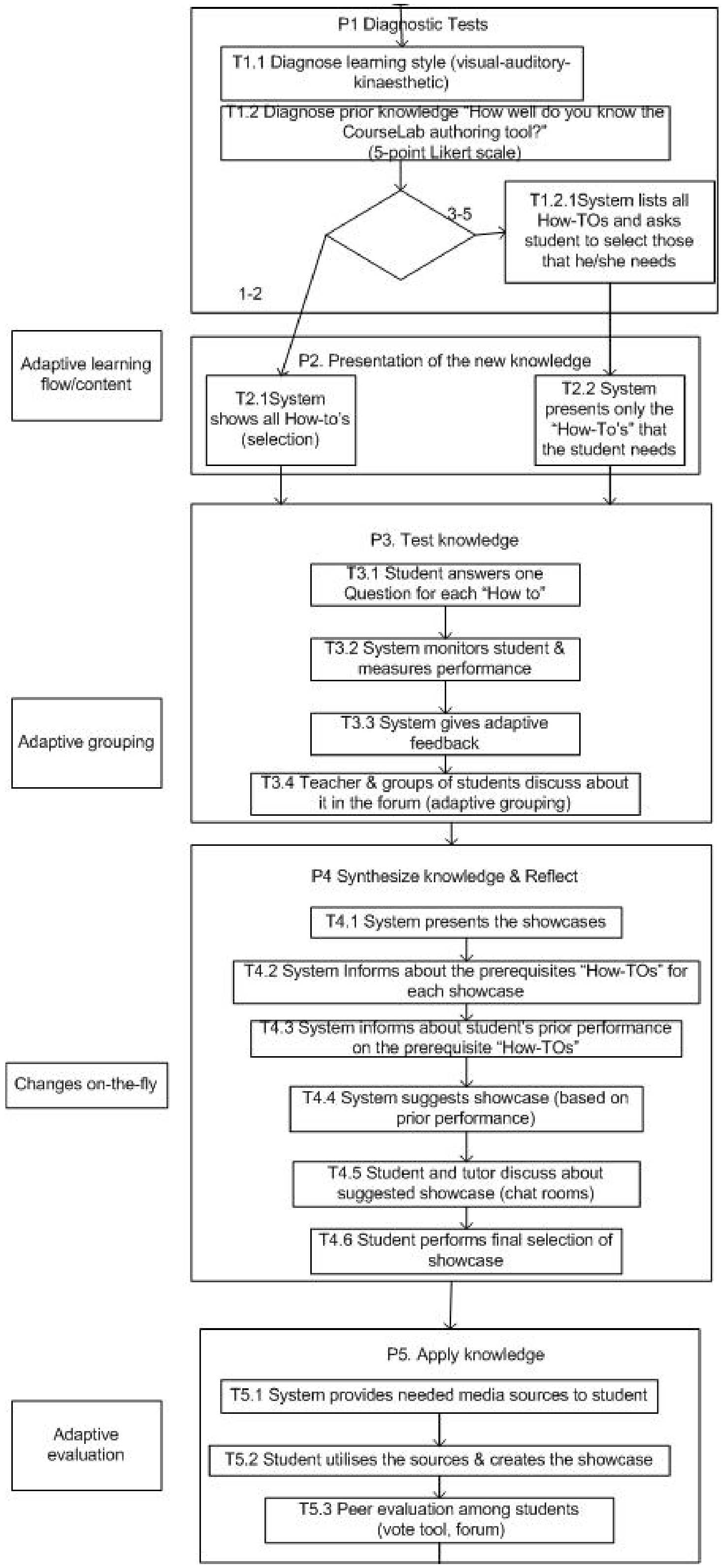


**Figure 14** Learning Flowchart of the "Learning CourseLab" course

### 4.1.2 The Educational Recommender System component

In the second phase of the learning scenario, the students are engaged with a number of learning activities ranging from 0 to 8, depending on the level of their prior knowledge and declared experience on the use of the e-learning authoring tool (i.e. CourseLab). As already mentioned, the learning activities are a set of "How-To's" that present key functionalities of the e-learning tool (i.e. CourseLab). During the instructional design of the adaptive course, I created as part of the learning strategy a 'relevancy matrix' between the pool of the "How-To's" and the pool of the "Showcases", which is shown below. Each showcase corresponds to an assignment for the student. Each showcase has one or more "How-To's" as prerequisites. Thus a showcase is suitable for a student if the student has mastered the knowledge of these specific "How-To's"

**Table 2 Associations between "How-To's" and "Showcases"**

| | H.T.1 | H.T. 2 | H.T. 3 | H.T. 4 | H.T. 5 | H.T. 6 | H.T. 7 | H.T. 8 |
|---|---|---|---|---|---|---|---|---|
| S1 | | x | x | | | x | x | |
| S2 | x | | x | x | | x | | |
| S3 | x | | x | | | | | x |
| S4 | x | | | | x | x | | |
| S5 | x | x | | | | x | x | |
| S6 | | | x | | x | x | | |
| S7 | | | x | x | x | x | x | |

Between the phase of the presentation of the prerequisite knowledge (i.e. "How-To's") and the synthesis of the showcase on behalf of the students, exists the phase which consists of the quiz. The goal of the quiz is to conclude on the students' knowledge. Thus, in the respective lesson plan, there exists another matrix that relates the questions with the "How-To's". (The lesson plan of the adaptive e-course is available in Annex 3, along with the template upon which it what based). So literally, the "How- To's", the questions of the quiz and the "Showcases" are interrelated. The recommender system, using properties and conditions of the IMS-LD specification (Level B), combines these relations, calculates a 'contiguity grade' for each "Showcase" based on the student's answers to the quiz and proposes to the learner specific "Showcases". Subsequently, the learner may discuss this suggestion with her tutor and decide whether she should follow it or pick another "Showcase" instead.

As already mentioned, the educational recommender system was implemented as part of the wider learning scenario and may be reused in every IMS-LD compliant player, such as the RELOAD Learning Design player[18] or the Astro player[19]or even modified in a compliant editor, like the RELOAD Learning Design Editor[20], the ReCourse Learning Design Editor[21], the CADMOS Learning Design tool[22] and others.

Figure 15 depicts the idea of recommending the proper "Showcase" after calculating the "contiguity grade" mentioned above. For the implementation of the educational recommender system the needed work was based on setting properties and rules ("IF...THEN...ELSE" rules) through a form-based user interface, so no technical knowledge (like scripting or XML knowledge etc) was needed for the creation of this particular component. The underlying challenge was to describe potential uses of this e-learning standard for adaptive courseware that do not require much technical knowledge and furthermore, to design, develop and evaluate the courseware (Mavroudi & Hadzilacos, 2012). It should be noted that this specific e-course was not tested in real classroom settings, since its aim was not to test its learning effectiveness, but to conclude on its implementation difficulty as this was perceived by a group of novice instructional designers.

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[18] http://www.reload.ac.uk/ldplayer.html

[19] http://tencompetence-project.bolton.ac.uk/ldruntime/index.html

[20] http://www.reload.ac.uk/ldeditor.html

[21] http://tencompetence-project.bolton.ac.uk/ldauthor/

[22] http://cosy.ds.unipi.gr/cadmos/

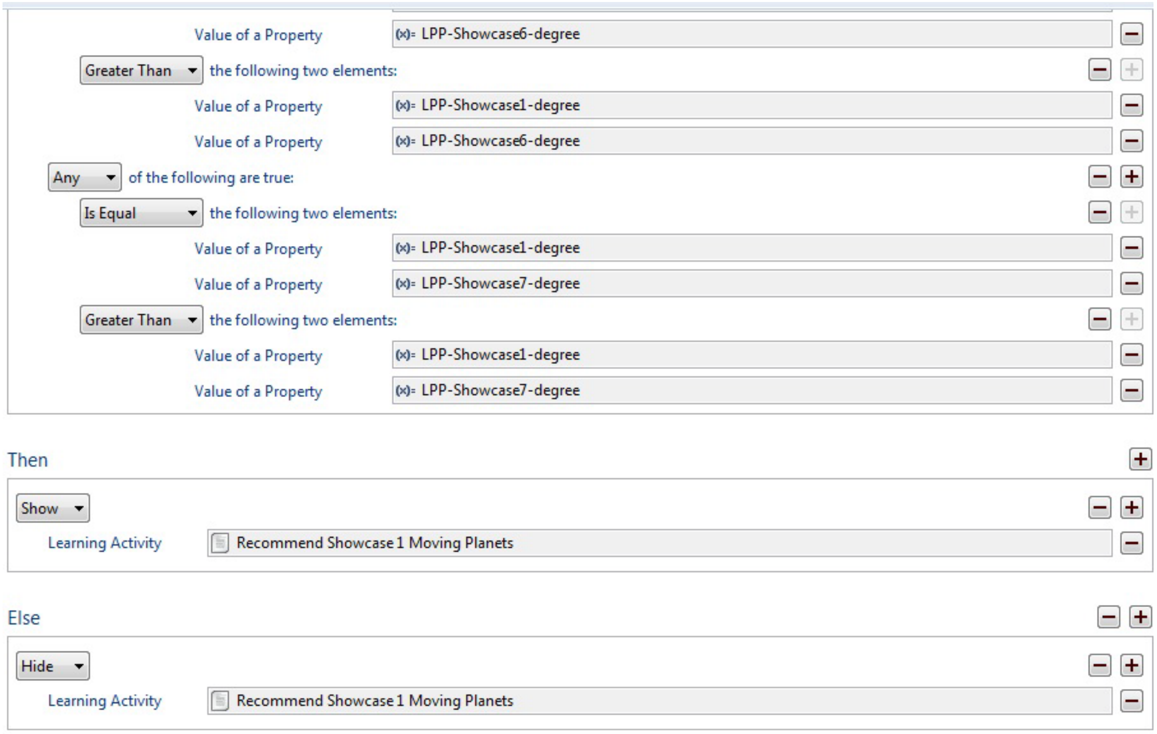



**Figure 15 The use of IMS-LD rules**

### 4.1.3 How the components of the adaptive e-course were evaluated by novice instructional designers

An online survey was conducted in order to assess the implementation difficulty and the complexity of the "Learning Courselab" adaptive e-course, as this was perceived by 12 novice instructional designers. The profile of the participants and the settings are described in detail in section 4.6. The adaptive e-course was the incarnation of a UoL that corresponds to the third implementation difficulty level, as already explained before. Participants answered that in order to create an adaptive Unit of Learning (UoL) that corresponds to the third implementation difficulty level, the developer needs to have average programming knowledge (n=12, mean = 2.5, standard deviation =0.7, in a five-point Likert scale where the respective statement in the online survey was "To create an adaptive UoL that has the same difficulty level with the 'Learning courseLab UoL', someone has to have good programming skills". A score of 'one' indicated disagreement with the statement and a score of 'five' indicated agreement with the statement). Also, they answered that in order to create an adaptive UoL that corresponds to the third implementation difficulty level, the developer needs to possess average to good technical knowledge (n=12, mean = 3.1, standard deviation =0.9, in a five-point Likert scale where the respective statement in the online survey was “To create an adaptive UoL that has the same difficulty level with the ‘Learning courseLab UoL’, someone has to have good technical knowledge”. A score of 'one' indicated disagreement with the statement and a score of 'five' indicated agreement with the statement). Finally, participants answered that in order to create an adaptive UoL that corresponds to the third implementation difficulty level, the developer needs to possess good knowledge of the IMS-LD specification itself (n=12, mean = 4.1, standard deviation =0.5, in a five-point Likert scale where the respective statement in the online survey was “To create an adaptive UoL that has the same difficulty level with the ‘Learning courseLab UoL’, someone has to have good knowledge of the IMS-Ld specification”. A score of 'one' indicated disagreement with the statement and a score of 'five' indicated agreement with the statement).

In addition, the novice instructional designers were asked to assign a grade between 1 and 7 that would correspond to the ratio usefulness/(implementation difficulty) of the educational recommender system included in the “Learning Courselab” UoL. The mean grade of their answers was 4,42 (n=12, st.dev=1.16). I also implemented another component: a ruleset that triggered an “alert” signal when a mismatch/conflict between the student self-assessment (phase 1) and the actual student performance (phase 3) was detected. In turn, this “alert” signal, triggered an activity through which the tutor and the student could discuss about the mismatch in a chat room and together decide the next step.) Again, the novice instructional designers were asked to assign a grade between 1 and 7 that would correspond to the ratio usefulness/(implementation difficulty) of that component. The mean grade of their answers was 4,75 (n=12, st.dev=1.42). Consequently, the perceived implementation difficulty was greater than its usefulness. Follow up semi-structured interviews revealed that the respondents based their answers on the effort that the “average teacher” needs to put in the implementation of the components. Thus, our initial hypothesis needed to be partially reclaimed and ways to engage the teachers and the other stakeholders that don't possess a good technical background needed to be discovered.

## 4.2 A Preliminary survey on adaptation methods

The table below shows the answers of ten participants who answered, through an online questionnaire the extent to which they adapt their teaching practices according to certain parameters using a 5-point Likert scale. A score of 'one' indicated disagreement with the statement and a score of 'five' indicated agreement with the statement “I adapt my teaching practices according to these parameters”. The participants' occupations (6 from Greece, 1 from Portugal, 1 from Malaysia, 1 from Cyprus and 1 from USA) were either instructional designers and/or educators teaching in schools. All answers but one (who gave grade 2) ranked learning style as an important or extremely important parameter (gave grades 4 or 5).

**Table 3 Adaptive learning parameters**

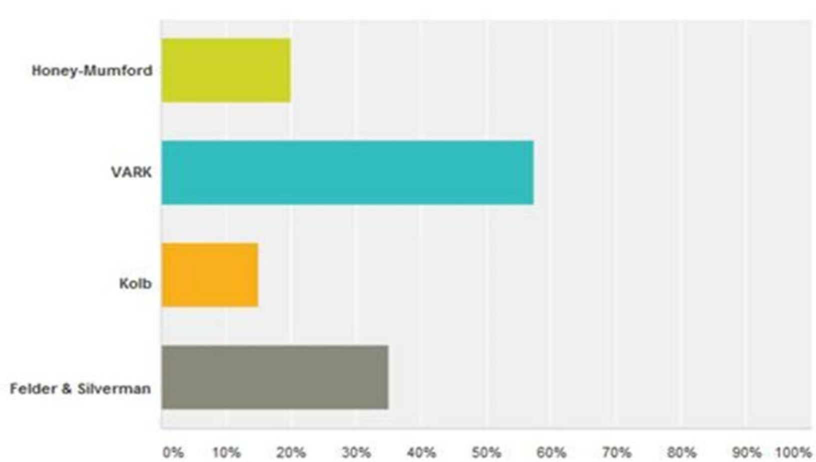
| | Mean | Standard deviation |
|---|---|---|
| Prior Knowledge | 3.90 | 1.19 |
| Learning Style | 4.00 | .816 |
| Learning Strategy | 4.30 | .949 |
| Time Availability | 4.00 | .943 |
| Learning Objectives | 4.10 | .994 |

A follow up discussion through a semi-structured interview aiming to elaborate on the answers of the questionnaire revealed that this educator would also like to incorporate learning style as a defining parameter for his teaching practices, if suitable tools were available. Finally, it seems that the participants believe in the added value of adaptive learning (with or without the use of technology). As one participant mentioned during the follow up discussions:

*“I think that the teaching process is not far away from a successful theatrical play. You can’t play every day the exact same performance for a different audience. You must check the audience response, have a great variety in the repertoire and adapt according to your audience. Repeating the exact same play again and again is not theatre, it is called cinema.”*

### 4.3 Learning style typology selection process

As already mentioned in Chapter 2, the most popular learning style models mentioned in the recent research literature are: 1) Kolb's experiential model, 2) VARK (Visual, Auditory, Read/Write, Kinesthetic) model, 3) Honey and Mumford model and 4) Felder & Silvermann model. These models were described to 40 active educators. In their vast majority they are working in secondary education schools. There is no known bias on the teacher sample used for the survey; however it was not a scientifically random sample. Teachers approached were those who have active contact with a teachers' union. The explanation of the models was in the form of a written description, avoiding domain-specific terminology, and it was conducted through an online questionnaire survey. Thirty-six of the educators live in Cyprus, 3 live in Greece and 1 in the UK. They were asked to select the model they think that it is closer to their everyday teaching practices (i.e. more applicable). The question was purposefully formed so that teachers could specify just one or several models as being "close to their practice"; there was no limit and no indication whether one or more were expected. The questionnaires were answered anonymously.




| Answer Choices | Responses | |
|---|---|---|
| Honey-Mumford Model | 20.00% | 8 |
| VARK Model | 57.50% | 23 |
| Kolb Model | 15.00% | 6 |
| Felder & Silverman Model | 35.00% | 14 |
| Total Respondents: 40 | | |

Figure 16 The results of the online survey

According to the results, 20% of the participants selected the Honey-Mumford model (8 votes), 57.50% of the participants selected the VARK model (23 votes), 15% of the participants selected the Kolb model (6 votes) and 35% of the participants selected the Felder & Silverman model (14 votes). Yasir & Sami, (2011) take for granted in their research that the VARK model " is one of the simplest and therefore, most widely influential model". This section confirms that argument via a scientific method.

## 4.4 Proposed strategy for adaptive e-Learning

The table below shows how the learning preference informs the design of learning activities. I suggested these mappings as part of the proposed adaptive learning strategy. The VARK model is used for the categorisation of the learning preference parameter.

**Table 4 Mappings between learning preferences and the design of learning activities**

| Learning Preference | Learning activities with |
|---|---|
| Auditory | Recordings, audio narratives |
| Visual | Diagrams, pictures, flowcharts, slides |
| Read/write | Web 2.0 tools (forum, chat, wiki), open ended questions, lists, essays |
| Kinaesthetic | Mobile learning, real life learning experiences |
| Mulitmodal | All the above |

Learner's prior knowledge (Görgün et al., 2005) and their learning style (Chen and Zhang, 2008) are two parameters often referenced in the recent literature being used for adaptation. The learning strategy was inspired by the guidelines of N. Fleming (the creator of the VARK test, it is discussed in more detail in section 3.4), but also by current trends in educational technology that have already proved in the wider educational industry their positive effects in the learning process (Web 2.0 tools, mobile learning). It further tries to combine these two strands so that: the selection of the media should not only be in accordance with the learning preferences, but also, in a second level should avoid cognitive load and related effects, like the split attention effect. This adaptive learning strategy was followed on the design of the e-courses mentioned in chapters 5 and 6.

## 4.5 Group-work in the design of adaptive e-courses by novice instructional designers

The case study described in this section was enacted as part of a 14-week graduate course on "Learning Design and Design of Educational Software" which was included in an MSc in Information and Communication Systems (ICS) program during the first semester of the academic year 2012-2013. The course is offered online and it combines weekly synchronous sessions (using the web conference technique) with asynchronous activities implemented through the university learning management system and via email. The asynchronous activities mainly facilitated a) instructor-to-student and student-to-student communication and b) access to learning materials, assignments, assignment grades and so on. To a lesser extent, the learning management system facilitated the students' familiarisation and experimentation with certain learning technologies, like Web 2.0 technologies.

Twelve students, aged from 25 to 45 years old, participated in the course. Students taking this course specialise in Educational Technology, usually for professional reasons. Six of them were active educators in different settings (elementary, primary, secondary and continuous/adult education), teaching diverse subject matters (informatics, mathematics, physics and others). Two of them were pre-service teachers and the remaining four had various non-teaching professions involving ICT. Four live in Cyprus and eight live in Greece. None of them had participated before in a lesson about Learning Design or Technology Enhanced Learning. All of them had completed their studies in tertiary education. During the academic semester, students submitted ten short weekly and two in-depth assignments.

The basic aim of the intervention was to make the students appreciate the interdisciplinary nature of the field of educational technology and the interplay of the various perspectives and dimensions involved in the design of a TEL artefact through a problem-based learning approach. On top of that, the use of IMS-Learning Design specification provided a formalisation of the teaching learning process through the metaphor of the theatrical play, leaving all the design decisions up to the learning designer. In parallel, the focus was also placed on Learning Design systems: two IMS-LD compliant systems were used by the students in order to author and preview their adaptive e-courses. The resulting learning environment was an Open Learning Environment (OLE) with tools, resources and activities suitable for the promotion of divergent thinking in a learning situation where multiple perspectives are valued (Hannafin et al, 1983). The learning tasks were designed so as to provide enough opportunity to the students for practice both the non recurrent (study LD theory, design learning scenario, employ an adaptive learning strategy and so on) and the recurrent aspects of the complex skill (drill the most commonly used functionalities of the tools and so on). That is why such a learning ecology was appropriate and why the 4C/ID model, which is described in the next section,  was a suitable model for our students' collaborative tasks.

### 4.5.1 Complex learning & 4C/ID model

The design of the intervention is based on the Four Components Instructional Design model (4C/ID), a model originally developed by Van Merriënboer et al. (2002), who suggested that environments for complex learning can have four interrelated components:

- Learning tasks that engage students in activities suitable for the development of the needed constituent skills, as opposed to activities where students need to study general information related to the skills.
- Supportive information that bridges what students already know to their work on the learning tasks. Tutors typically refer to this type of information as "the theory", often presented in lectures and textbooks.
- Just-In-Time (JIT) information relates to the constituent skills that should be performed similarly in different problem situations. It offers students information about the procedural knowledge they need to obtain in order to perform the recurrent skills. Examples of this type of information include instructions provided during students' practice, where tutors are acting as an "assistant looking over your shoulder" (Van Merriënboer et al., 2002).

- Part-task practice which is required if a very high level of automaticity of particular recurrent aspects is necessary. Examples of part-task practice are "drilling children on multiplication tables and playing scales on musical instruments" (Van Merriënboer et al., 2002). An example of part-task practice in training design of an air traffic controller might involve critical recurrent constituent skills in terms of safety, for example, identifying risky air traffic situations from a radar screen (Van Merriënboer et al., 2002).

Two main principles of the model are: 1) scaffolding and fading (i.e. withdrawing help as the learner progresses) and 2) that in each learning task, the complexity of the sub-tasks should gradually increase. Finally, the model aims at the automation of the recurrent aspects of the task, while promoting deep learning for its non-recurrent aspects. According to Van Merriënboer et al. (2003) complex learning involves "the integration of knowledge, skills and attitudes, the coordination of qualitatively different constituent skills and the transfer of what is learned to daily life or work settings". According to Merrill (2002), the model is based on problem-based learning and also focuses on a learning activity that employs complex cognitive skills.

### 4.5.2 The contextual settings of the Learning Design intervention

The intervention took place between the 10th and the 13th week of the course (from the time that the assignment was announced to the students to the time that the students' products were uploaded to the Moodle LMS). The two last sub-tasks mentioned in the previous section were included as sub-topics in the final exams, due one week after the end of the 14th week of the course. The participating roles in this intervention were: a) the tutor, who was the main person responsible for the course in general and was basically responsible for the support of the students with the more "theoretical aspects", b) the assistant (the author of this thesis), who was the main person responsible for the more practical parts i.e. of the design of the worked-out examples and completed scenarios and c) the students. In terms of scaffolds, except those mentioned above, one web conference meeting (where the students, their tutor and the assistant participated) was devoted to the enlightenment of the difficult parts of the theory. Additionally, support and advice was provided by the assistant via a dedicated online forum, Skype and email. It revolved mostly around tool functionality issues, but secondarily also involved other issues like ideas about adaptation parameters. Towards this end, the paper by Economides (2008) was also included in the suggested readings. The support included synchronous as well as asynchronous discussions. Student evaluation rubrics and performance standards were designed collaboratively by the tutor and the assistant (the students' evaluation rubric is shown in Annex 1). The twelve students who participated in the course were asked to work collaboratively and consequently, three groups were formed. In each group there was at least one member who was an educator (and, as such, he/she was familiarised with lesson planning procedures) and at least one member that was an informatics professional.

More specifically, the students had to deal with the following tasks:

• read the respective LD theory, which, for the scope of this intervention, comprised two chapters from a previous master thesis on the topic, the IMS-LD Information model (IMS GLC, 2003b), the IMS-LD Best Practice and Implementation Guide (IMS GLC, 2003c), one chapter from the text book (Koper & Tattersall, 2005) and lesson slides

• study worked-out examples of adaptive learning scenarios and their incarnations in the form of Units of Learning; worked-out examples and their corresponding UoLs were administered to the learners (two examples of level A and two examples of level B and their corresponding UoLs)

• conceptualise and design a learning scenario for adaptive learning close to their interests (i.e they could select any subject matter); towards this end, a learning scenario template accompanied with the description of the semantics of all its fields was administered to the learners

• draw a UML activity diagram to demonstrate the different phases, actors, interactions, synchronisation points between actors and learning strategies used in the learning scenario-see examples in (IMS GLC, 2003c); the UML activity diagram was used as a means of visualization of the e-course workflow, similarly to the flowcharts diagrams that are being used to the non-adaptive eLearning field.

• develop learning materials and adaptive learning strategies that can be implemented fully or partially with the use of the IMS-LD methodology

• install and use the authoring tool (i.e. the MS-LD compliant editor), as well as, a tool to preview their work (i.e an IMS-LD compliant player); user guides were provided

• implement the respective adaptive Unit of Learning (i.e. adaptive e-learning lesson) using the authoring tool and frequently preview the results using the player

• discuss the difference concerning the implementation difficulty between a non-adaptive (Level A-compliant) UoL and an adaptive (Level-B compliant) UoL

• reflect on the concepts of "re-usability", "learning content", "learning services", "learning activities" and the use of widgets (see Annex 2)

• reflect on their experience by proposing a model of guidance and support in an imaginary scenario where they had to lead a multidisciplinary team in order to construct adaptive Units of Learning -this task was included as a topic in the students' final exams

• map textual descriptions of a set of events (what constitutes an event was described in the previous section) against the type(s) of adaptation functionality they implement (e.g. learning flow adaptation, content-based adaptation, interactive problem-solving support, adaptive user grouping etc), this task was also included as a topic in the students' final exams

### 4.5.3 Data collection methodology

Empirical results were gathered from the following data collection sources:

1. the web-conference recording session,

2. posts in the dedicated forum in the university LMS,

3. answers on an online survey questionnaire and follow-up semi-structured interviews

4. the final products of the students i.e. their designed artefacts

5. the answers of the students in the hypothetical scenario (a final exams question)

6. the log-files of the LMS system and the IMS-LD player (the online version)

Some remarks concerning the data collection methodology:

The online survey questionnaire was distributed to the students immediately after the end of the semester and the semi-structure interviews followed a few weeks afterwards. The interviews duration was 20 minutes in average and they were conducted through electronic means (VoIP and the Elluminate live! ™ web-conference software, according to the student's preference).

The log files provide some evidence about the type and the frequency of students' interactions with the system, but it is not a clear and reliable indicator concerning their engagement and participation. This is due to the fact that, concerning the LMS forum, it was only used for the "official story" of the students' interactions, since from the interviews it became evident that the students used Skype™ to collaborate on their assignment. As far as the IMS-LD complaint player is concerned, each student had access both to the online version but also to their local, offline version of the player that they used to preview and test their UoLs.

Participation in the online survey, in the discussion forums or in the personal interviews was voluntary. Also, none of the above contributed towards the students' final grades. The return rate of the online survey was 100%, since all the students completed the survey. The return rate of the semi-structured interviews was 67%, since eight students participated (the remaining four students were either not able or willing to participate). Finally, the students were aware of the fact that the web conference sessions and the semi-structured interviews were recorded.

The students felt that the aspect of genuine collaboration was addressed satisfactorily (n=12, mean=4.6, standard deviation=0.6 in a five-point Likert scale where the respective question in the online survey was "This task favoured genuine collaboration". A score of 'one' indicated failure in satisfying the goal and a score of 'five' indicated success).

In the online survey questionnaire the students were asked to reason about the score that they had assigned in the previous question. The open-ended question was used in the survey in order to provide the students with the opportunity to make suggestions, comments and complaints related to their learning experience (Kanuka & Anderson, 2007). The transcripts of the open-ended questions were analysed using the Grounded Theory approach (Glaser & Strauss, 1967; Strauss

& Corbin, 1994), a content analysis method that allows key themes to be emerged mostly from textual data through coding cycles. The codes, concepts and categories emerged were tested against the interview transcripts.The results are shown in the textbox, where concepts are presented in the form of bulleted lists and the emerged themes are in capital letters.

TEAM MEMBERS COLLABORATED IN ORDER TO RESOLVE PROBLEMATIC SITUATIONS

- Collaboration as a means of resolving tool issues and providing help
- Collaboration in order to compensate of lack of supportive material

ACTIVE TEAM MEMBERS HAVE A POSITIVE ATTITUDE TOWARDS COLLABORATION

- Positive attitude/comments towards collaboration
- Collaboration perceived in terms of equal contribution by team members

COLLABORATION WAS FOSTERED THROUGH A SCHEDULE

- Having a schedule (task schedule, meeting schedule)
- Collaboration via frequent meetings between team members
- Conflictions with other students' obligations hinder participation

COLLABORATION WAS SUPPORTED BY A RANGE OF CSCL TOOL AND PRACTICES

- Collaboration via online meetings
- Collaboration perceived in terms of efficient communication
- CSCL mediated via students' designed artefacts (lesson scenario, UoLs)
- Tools and practices covered various aspects of CSCL (skype meetings for synchronous communication, forum for asynchronous communication, google docs for theoretical parts, desktop sharing for technical or practical issues)

COLLABORATION SCHEMATA

- Limited collaboration between teams
- Role/task distribution within teams
- Frequent controls and corrections

Figure 17 **Concepts and themes concerning the collaboration aspect**

Concerning the collaboration via the forum, five discussion forums (each addressing a separate aspect of the students' assignment) were set up on the Moodle LMS. Two of them ("forum 1" and "forum 2") were created and initiated by the tutor and the remaining three by one particular student ("forum 3", "forum 4" and "forum 5"). The data presented in the table below indicate the frequency of student and instructor participation, the total number of messages in each thematic forum (Hara, Bonk & Angeli, 2000) and the number of students that participated in each forum discussion.

**Table 5 Participation in the online forum**

| Name (Created & initiated) | Total number of messages | Total number of instructors's messages | Number of student participants in the forum |
|---|---|---|---|
| Forum 1 (by the instructor) | 20 | 9 | 4 |
| Forum 2 (by the instructor) | 9 | 3 | 4 |
| Forum 3 (by the student) | 4 | 1 | 2 |
| Forum 4 (by the student) | 29 | 8 | 7 |
| Forum 5 (by the student) | 11 | 10 | 1 |

The dimensions of content analysis using CSCL tools, such as an online forum, that are commonly employed are: participation, cognitive processing and social interactions (Sing and Khine, 2006). The data of the table above gives a rough idea of the participation aspect. The five discussions included altogether 73 postings. The proportion of postings by the instructors was 42% (31 messages). This relatively large proportion can be attributed to the fact that the forum was perceived by the students as the means of getting help and support primarily from the professor and the assistant. In the context of this distance education setting, communication with them exclusively took place online. From the online survey and the semi-structured interviews it became evident that the students frequently consulted the forum. This is confirmed by the web analytics that enable the user tracking functionality of the LMS, which revealed 763 views of forum discussions (in the forums 1-5 and during the time period that the intervention took place).

Concerning the types of postings, various content analysis schemes to analyse transcripts of online asynchronous discussions exist (Hara, Bonk & Angeli, 2000; De Wever et al, 2006). For the scope of this case study, the theoretical framework of Järvelä and Häkkinen (2002) seemed most appropriate, since it proposes a categorisation of the postings which discriminates between: (a) theory, (b) new point or question, (c) experience, (d) suggestion, and (e) comments. The message served as the unit of analysis for this categorisation. The students' messages in the forum were analysed and coded independently by the assistant and the author of the master thesis included in the students' readings. The inter-rater agreement percentage was at first 81%, which reached 95% after discussions about the disagreements between the two coders. The final results are depicted in the figure below. Out of the 42 students' messages posted in the forum, 1 message (2%) concerned LD theory, 9 messages (21%) introduced a question or a new point, 10 messages (24%) suggested a solution, 10 messages (24%) reflected students' learning experience and 12 messages (29%) mostly commented on various other aspects related to the intervention at stake.

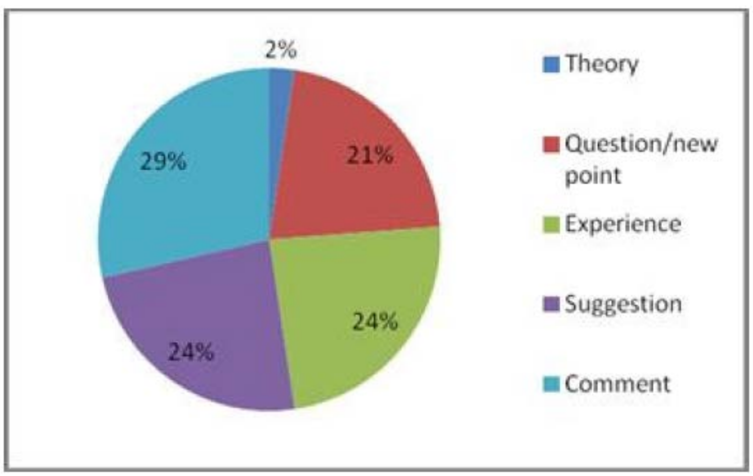



Figure 18 Distribution of posting types

The forum served as a common place of reference that included a significant number of suggestions concerning the above issues. It should be noted however that communication between the assistant tutor and the students was also to a lesser extent enacted through email and Skype. From the online survey it can be concluded that, overall, students felt that the support they received was very satisfactory (n=12, mean=4.4, standard deviation= 0.8 in a five-point Likert scale where the respective question in the online survey was "The support I received via the forum/Skype/email was satisfactory". A score of 'one' indicated failure in satisfying the goal and a score of 'five' indicated success).

### 4.5.4 Bridging the gap between LD theory and IMS-LD practice

The degree in which the intervention accomplished the goal of bridging the gap between theory and practice was perceived by the students as very satisfying (n=12, mean=4.4, standard deviation= 0.9 in a five-point Likert scale where the respective question in the online survey was "The task helped me in bridging the gap between theory and practice". A score of 'one' indicated failure in satisfying the goal and a score of 'five' indicated success).

Two indicators were evaluated positively on this criterion: Consistency between the learning scenario, the UML workflow diagram and its incarnation in the form of a Unit of Learning (see Annex 1). Evidence that the students could distinguish the difficulties that arose due to the user-friendliness of the tools they used (or the absence of it) from those that would remain the same regardless of the IMS-LD compliant tool being used. The latter implies difficulties inherited in the complexity of the conceptual framework of the IMS-LD (the workflow, the theatre metaphor, the adaptation elements).

Concerning the first indicator, all the groups managed to achieve consistency between the learning scenario and the UoL, whereas none of the groups managed full consistency between the UML activity diagram and the learning scenario (or the UoL), although the students were familiarized with UML activity diagrams before their enrolment in the course. As far as the second indicator is concerned, all the students that were interviewed showed explicit evidence that they could distinguish the IMS-LD specification from the tools that implement it. An example of what constituted explicit evidence concerning the issue is depicted below:

(Student) *If you have understood the IM-LD specification and you know that you have to cope with activities, roles, environments etc, and furthermore, if you can distinguish levels A, B & C, then -using the ReCourse editor or any other IMS-LD compliant tool -you won't be having any issues, from the specification perspective. If you have conducted a good planning on how to implement it (i.e the learning design) then it's a purely technical matter and it depends on how familiarised you are with the program.*

In addition to the indicators mentioned above, the authors also detected some student statements that on the one hand exemplified deep understanding concerning the fact that the UoL is the incarnation of a learning design, but, on the other hand, they did not fall into either of the two categories mentioned above. An example is the following:

(Student) *After this assignment everything was clear to me, I didn't need to study (for the final exams), only some lectures. The only thing I took with me in the exams (students were allowed to bring with them any learning materials they wished for the final exams) was the printed form of the manifest.xml of the UoL we had created. The entire course is included in this file, what else did I want? [..] declarations, metadata, properties, activities, roles-parts, roles.., everything is in there. If you can conceive this, this XML file can tell you all you need to know.*

Additionally, from the discussions held with the students it became evident that they could abstract their learning experiences. By the time that the interview took place one student (an informatics professional) had already managed to transfer the knowledge gained from the intervention into her workplace. In particular, she mentioned that she had applied the design philosophy behind the IMS-LD compliant tool into a new e-business system in her work, in order to better conceptualise its information model since she felt that it was similar to the IMS-LD Information Model (i.e. resembling the metaphor of a theatrical play). Another student, who used two different IMS-LD compliant editors, could effectively communicate to the assistant during the semi-structured interview their different affordances and intended uses.

#### 4.5.5 Learning progress

As mentioned in section "Complex learning & 4C/ID model", two sub-topics about adaptive learning were included in the students' final exams, aimed at checking how the students' learning about the topic at stake (i.e. adaptive learning designs) had progressed over time. The score of each team (i.e. the average score of the team members) both for their assignments and for the final exams was calculated. The results are depicted in the table 6.

**Table 6 Scores & learning progress**

| Team | Assignment (out of 10) | Average exam scores (out of 10) |
|---|---|---|
| Team A | 8.5 | 7.3 |
| Team B | 9 | 9.3 |
| Team C | 9.5 | 9.7 |

As it is shown in the table, there is a strong positive correlation (r=.92, p=.25) between the scores in the assignment with the scores (in the topics about adaptive learning) in the final exams. The correlation between the students' scores in the assignment and the students' scores in the final exams is depicted in the table below. The t-test still reveals a positive correlation between the two variables (r=.501, p = .01). Note that Kolmogorov-Smirnov tests were performed to test the normality presupposition. With regards to the hypothetical scenario where the students had to lead a multidisciplinary team in order to construct adaptive Units of Learning, most of them reproduced their own variations of the 4C/ID model.

### 4.5.6 Complex learning in today's digital world: CSCL or CSCD?

**Background and rationale**

There is a growing body of research on co-design for learning purposes approached from two major perspectives:

- In terms of specific-purpose tools; for example in (Hernández-Leo et al, 2011) a web-based authoring environment, "LdShake", is presented as a tool that enables the co-edition and social network-oriented sharing of learning designs created using a general rich text editor.
- In terms of collaborative design of ICT-infused learning scenarios by teachers, as a form of their professional development. This approach sees teachers as designers (Voogt et al, 2011) and is aligned with the well-established "learning by design" notion (Kolodner et al., 2003), while it acknowledges that the active involvement of the teachers in the LD

process might have a positive impact on their professional development and in turn, on student learning (Kali & McKenney, 2012).

In parallel, the question of how we could apply to LD insights derived from the discourse with other design disciplines is an interesting aspect that has begun to flourish and to attract the attention of the stakeholders (Mor & Craft, 2012; Mor et al., 2013). Examples of initiatives that embrace this aspect include:

- The Learning Design studio (LDS), an effective manifestation of the Design Inquiry of Learning (DIL) model. The latter combines an inquiry-based learning approach with a design-based scientific paradigm. The former is modelled after the tradition of studio-instruction in arts and design disciplines, such as architecture, its main characteristic being the students' on-going group work on design challenges in a domain of practice (Mor & Mogilevsky, 2013).
- The Design Principles Database (DPD), which aims at synthesizing emerging design knowledge about the use of technologies for education (Kali, 2006).
- The International Journal of Designs for Learning, a journal dedicated to publishing descriptions of artefacts, environments and experiences created to promote and support learning in all contexts by designers in any field.

Creation of artefacts and collaboration were the two most pivotal design patterns, while the following design principles were incorporated in the intervention:

- use open-ended construction tools
- engage learners in a complex project
- use multiple representations
- provide knowledge representation and organisation tools
- promote autonomous lifelong learning
- provide students with templates to help reasoning
- provide just-in-time data to students
- connect to personally relevant contexts
- encourage reflection

### 4.5.7 Implications

The purpose of this section is to provide insights concerning the interactions between the students with their digital artefacts, as well as their social interactions.

In particular, focus is placed on the role of the mediating artefacts viewed from a distributed cognition framework perspective, since the latter "is specifically tailored to understanding interactions among people and technology" (Hollan et al, 2000) in terms of not only what people know, but how they go about using what they know to do what they do (Hollan et al, 2000). For the scope of this work (where the participants' observation was not possible) distributed cognition is being viewed from a situative perspective (rather from a cognitive one) in which knowledge exists in the way that social groups communicate, make use of symbols, tools and designed artefacts and understanding is a process of negotiating the meaning of these objects with others (Hewitt and Scardamalia, 1998). Interesting points in the intervention at stake are: 1) the use of student-created designed artefacts and 2) the students' spontaneous use of CSCL tools and techniques, in order to mediate their learning and facilitate the design process.

The discussion is mostly based on what is presented in the section titled "Data analysis and results", sub-section titled "Collaboration". As already mentioned in that section, CSCL emerged mostly within teams, whereas among teams it has commonly happened in the forums. Also, with regards to the collaboration schemata: roles and subsequent tasks distribution among team members: additionally frequent controls and corrections took place. CSCL was perceived by the team members in terms of efficient communication (i.e. how well ideas and experiences were communicated among team members) and equal contribution to the tasks. The students' constructed mediated artefacts were: the lesson scenario and the UoL. As already mentioned, the students used a variety of CSCL tools and practices: Skype meetings for synchronous communication, forum for asynchronous communication, Google docs for theoretical parts (i.e. related to the creation of the learning scenario), desktop sharing for technical or practical issues (related to the creation of the UoL) in a spontaneous mode. Concerning the organisational and social settings that superseded the learning process, students acted as lifelong learners, since they took full responsibility of their progress by preparing a shared plan of action (task schedule, meeting schedule) and organising frequent online meetings. As it was expected, participation was hindered by students' obligations (family obligations, work obligations). On the other hand, having a positive attitude towards collaboration and being an active member within a team seem to be interrelated. Finally, collaboration between students was practiced as a means of resolving tool issues, providing help and compensating the lack of supportive material.

In conclusion, we argue that the incorporation of a CSCL tool in a way that fosters a variety of practices in today's digital world where learners create and share their artefacts could be an indispensable characteristic of an all-encompassing IMS-LD compliant environment. More specifically, concerning the desktop sharing feature in the case of CSCD of the UoL, it will enable the "what you see is what I see" (WYSIWIS) design principle which is suggested in previous work for designing at a distance via real-time designer-to-designer interaction (Scrivener et al, 1993). The benefits of Web 2.0 tools (such as forum, chat, Google docs etc.) have been extensively discussed in the CSCL-related literature in general and especially with regards to professional development (Cochrane and Narayan, 2013). In addition, a shared view of the designed artefacts along with the use of Web 2.0 tools would foster the communication and the support coming from the experts, something that seems to be vital in the case of novice developers.

### 4.5.8 Discussion

This work  is a design case where CSCL and CSCD took place, in which it is evident that the students were not highly engaged  with the Learning Design aspects that are closely related to pedagogy. On the one hand, it has been argued that students who follow Learning Design courses offered via computer-science related programs of study (in this case, the ICS program) face difficulties in the design of learner-centred courses which revolve around the design of appropriate lesson plans (Kordaki, Papadakis & Hadzilacos, 2007). In addition, the creation of learner-centred e-courses was not the focus of this particular intervention, although exemplifying sound pedagogical choices was considered an advantage (as one can see in Annex 1).

With regards to our methodology, the idea of conducting semi-structured interviews with the possible stakeholders for eliciting design requirements is not new, since they can provide direct access to 'experience' (Silverman, 2000). For example, Luck (2000) suggests requirements about the inclusive design of a building based on interviewing people with disabilities. Where there were conflicting requirements, these were resolved during dedicated steering group meetings. Yet, a building is a physical entity and as such it can have only one facade, whereas this is not true for a digital environment intended for collaborative design of Units of Learning. Since multiple views in such an environment would be possible, future plans include further work in the requirements analysis by identifying possible different requirements for the two main groups: teachers and informatics professionals. Yet, no conflicting requirements were noted in our case.

The implications of the case study presented in this chapter confirm the results of D. Nurjanah (2013) from the University of Southampton towards the importance of CSCD in the authoring process of adaptive eLearning Units of Learning. In her PhD thesis, she addressed the question of how teachers can collaborate in authoring adaptive learning resources and be aware of what is happening in the authoring process. In addressing this question, she extended the functionality of an open source IMS-LD compliant tool, the same tool that was used in the work described herein, with a module for asynchrorous collaboration for small groups of instructional designers. She divided the participants of her research in two groups: one that used the default version of the tool and one that used the collaborative version of the tool. She concluded that the instructional designers who worked with the collaborative version of the tool had higher workspace awareness and their UoLs were better than those produced by the group working with the standard version of the tool.

In addition to CSCD, the provision of templates to help students articulate their reasoning  seem also a useful functionality. As such, it was embedded in the design of a user-centered digital environment intended for the creation of adaptive e-courses (Chapter 7).

**Acknowledgements:** For the authoring of the Units of Learning the ReCourse LD editor was used. Also, to edit the HMTL and XML files incorporated in the UoLs I used the open source tool, Notepad++ editor. Finally, a web-server I configured and setup by under the domain name of the Open University of Cyprus, using the Astro LD player. All the above tools are open source solutions. The scenario template was a revised version of previous similar work conducted for the scope of GRAPPLE project ( http://www.grapple-project.org ), which was an EU funded IST FP7

project (from 2008 to 2011). The intended usage of the GRAPPLE learning scenario template was meant for learning designs that exploit the IMS-LD specification.

## 4.6 Annexes

**Activity evaluation questionnaire**

1. The activity had clear objectives (1=not al all,…, 5= very much)

2. The activity helped me to associate the LD theory with the LD practice (1=not al all,…, 5= very much)

3. The activity encouraged genuine collaboration (1=not al all,…, 5= very much)

4. Could you describe how did collaboration happen? (between teams and within teams collaboration)

5. The support I received via forum/skype/email was sufficient (1=not al all,…, 5= very much).

6. What kind of support is needed in order to help students to complete successfully the activity tasks?

7. a) The scenario template σεναρίου was useful (1=not al all,…, 5= very much), b) Why?

8. a) The worked-out scenario example was useful (1=not al all,…, 5= very much), b) Why?

9. To create an adaptive UoL that has the same difficulty level with the 'Learning courseLab UoL', someone has to have good programming skills (1 = I disagree completely, ..., 5 = I agree completely)

10. To create an adaptive UoL that has the same difficulty level with the 'Learning courseLab UoL', someone has to have good technical knowledge (1 = I disagree completely, ..., 5 = I agree completely)

11. To create an adaptive UoL that has the same difficulty level with the 'Learning courseLab UoL', someone has to have good knowledge of the IMS-LD specification (1 = I disagree completely, ..., 5 = I agree completely)

12. What knowledge and/or skills are needed in order to create an adaptive UoL that has the same difficulty level with the ‘Learning CourseLab’ UoL?

13. In the ‘Learning Courselab’ UoL a learning strategy proposes the suitable “Showcase” to the student by taking into account his prior performance in the questions associated with the “How-To’s”. Open the e-course with the LD Editor and study the ruleset that implements this specific strategy. Next, assign a grade between 1 and 7 that corresponds to the ratio usefulness/ (implementation difficulty), provided that you wish to exploit the adaptive feedback method in your course. Specifically, study the rules 6-13 of the ruleset named "Support learning material".

14. Another case of adaptive feedback implemented in the ‘Learning Courselab’ course is the following: the student declares the degree of her prior familiarisation with the Courselab tool. If the student declared high degree of familiarization with the tool, but his score to the test is low then the system points out to the student this discrepancy (i.e. the discrepancy between the perceived and the actual knowledge), notifies her tutor about it and automatically displays a chat room where the student and the tutor can discuss about it. Similar to the previous question, study only the ruleset that implements this strategy and assign a grade between 1 and 7 that corresponds to the ratio usefulness/ (implementation difficulty), provided that you wish to exploit the adaptive feedback method in your course. Specifically, study the 5$^{th}$ rule of the ruleset named "Support learning material".

**Annex 1: The students' evaluation rubric**

A. Answer in the question of Annex 2 (15 points)

Clear and concise answers concerning the concepts: re-usability, learning material, learning services, learning activities, widgets

B. Unit of Learning (40 points)

1.1. Technical integrity/excellence (15 points)

1.2. In accordance with the learning scenario (25 points)

C. Learning scenario (30 points)

1.3. Are all the fields satisfactorily completed/addressed? (10 points)

1.4. Do the students address thoroughly the topic of each field? Is it evident that they have understood the semantics of the field? (10 points)

1.5. Is the workflow diagram correct? Is it fully consistent with the learning scenario? (10 points)

D. Overall impression (articulated answers, authenticity, within word limits, pedagogical rationale and roles, complexity of adaptive strategies: does it combine more than one adaptive strategy? If yes, how many? The combination concerns the same or different phases of the scenario?) (15 points)

**Annex 2: A question that was included in the students' assessment**

Upload and run the completed (ready-made) UoLs to the LD player in order to preview the respective e-course and to formulate an initial idea about their design and enactment, as well as, the degree and the nature of their re-usability. In order to answer to the latter think that the reusability might entail processes and justifications like the following:

- remove this learning content, keep the lesson structure intact and insert my own content

- remove this learning content, change the lesson structure by adding or removing phases or learning activities and also insert my own learning content,

- …. etc

Please describe (in no more than 150 words) your learning experience. Having practiced the above, what do you think about the concepts of "learning content", "learning services", "learning activities"?

By now, you must have read two chapters from the master thesis. The process of learning design described in a chapter of the master thesis integrates some widgets. Have you understood how they can be used?

**Annex 3: The template and the worked-out example of a scenario for adaptive learning**

**A. Learning Scenario Template**

Literally speaking, the Unit of Learning is the incarnation of their learning scenario.

| | |
|---|---|
| **Scenario title** | |
| **Filename (.zip)** | |
| **Date** | |
| **Authors/Creators** | |

**Context[23]:**

**Short description:**

**Learning objectives[24]**:

**Learning strategies[25]:**

**Roles**:

**Prerequisites**:

**Learning flow (step-by-step)**:

1…

2….

---

[23] 'Context' refers mostly to the educational context, which could be school education (also mention grade and relationship with the curriculum), higher education (also mention educational program title), training, adult education, informal learning etc.

[24] You can use action verbs that are in line with the Bloom's taxonomy of Learning goals/

[25] More information about learning strategies are available at: http://www.nwlink.com/~donclark/hrd/learning/id/4c_id.html

3….

**Description of course adaptation**[26] **(**not applicable in case of an IMS-LD Level A scenario)**:**

**- Completion rule:**

**- IMS-LD elements used**:

| **Name** | **Write X if it applies to your scenario** |
|---|---|
| Properties | |
| Conditions | |
| Notifications | |
| Global elements | |
| Monitoring services | |
| Other external services (chat, widgets,..) | |

**Learning flowchart diagram:** Please use the conventions adopted in the IMS- LD Best Practice and Implementation Guide.

**B. Worked-out scenario example for the 'Learning CourseLab' course**

| | |
|---|---|
| **Scenario title** | Learning CourseLab course |
| **Filename (.zip)** | CourseLab course (IMS-LD compliant) |

[26] This could be related to: learning flow, students' grouping (in the case of computer supported collaborative learning), content presentation, feedback, evaluation etc.

| | |
|---|---|
| **Date** | 09/09/2012 |
| **Author(s)** | Anna Mavroudi |

**Context:** training, adult learning

**Short description:**

This Unit of Learning aims at familiarizing students with the Courselab capabilities. The UoL consists of five phases, each containing numerous learning tasks: 1. Diagnostic evaluation concerning prior knowledge and learning style, 2. Presentation of the new knowledge, 3. Test new knowledge, 4. Synthesize knowledge and reflect, 5. Apply knowledge.

**Learning objectives**:

After the end of the course the student will be able to:

- Apply the basic functionalities of the CourseLab tool
- Apply the advanced functionalities of the CourseLab tool
- Synthesize the acquired knowledge and skills in order to implement one "Showcase", given that the needed learning resources will be provided to her

**Learning strategy:**

Students will use the resources that correspond to the set of "How-To's" and the set of "Showcases". Students are called to explore the "How-To's" (according to their needs) and then synthesize their knowledge in order to create one of the "Showcases". Below you can see the list with the "How-To's" and the "Showcases".

"How-To's"

1. How to use popup window objects
2. Dragging and dropping objects
3. How to use Balloon objects
4. How to build complex question feedback
5. How to program Slide transitions
6. How to use the Timeline of the Frame

7. Quizzes in CourseLab
8. How to comment software simulation

“Showcases”

1. Example. Moving Planets
2. Example. Role-playing trainings
3. Example. Software Simulation
4. Example. First Aid For Electrical Accidents
5. Example. Language Teaching. Russian Alphabet
6. Example. PowerPoint Import
7. Example. Alexander the Great

Adaptive Learning strategy: below you can see the ‘relevancy matrix’ between the pool of the “How-To’s” and the pool of the “Showcases”.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. Moving planets | | x | x | | | x | x | |
| 2 Role-playing trainings | x | | x | x | | x | | |
| 3 Software simulation | x | | x | | | | | x |
| 4 First Aid For Electrical Accidents | x | | | | x | x | | |
| 5 Language Teaching | x | x | | | | x | x | |
| 6 PowerPoint Import | | | x | | x | x | | |
| 7 Alexander the Great | | | x | x | x | x | x | |

Table Associations between simple tasks (How-To’s) and composite tasks (Showcases)

From the table above, we can assume that some “showcases” require the synthesis of prior knowledge which can be acquired through the study of the “How-To’s”.

The e-course adapts the learning activities to the learner’s prerequisite knowledge.

In this specific learning scenario, the learning process follows a deductive-inquisitory approach since it presents information to the learners and then the learners themselves produce complete examples of work as assignments[27].

**Roles**: students, tutor, system

**Prerequisites**: Basic familiarization with any course authoring tool

**Learning Flow (step-by-step)**: See the description on section 3.2.1

**Description of course adaptation (**not applicable in case of IMS-LD Level A scenario)**:**

-the system adapts the content based on the results of the diagnostic phase

- the system adapts the content presentation based on the learning style mode of the student (visual, auditory, kinaesthetic etc)[28]

- the system adapts the content based on the student performance in the quiz

**IMS-LD elements**:

| **Name** | **Write X if it applies to your scenario** |
|---|---|
| Properties | X |
| Conditions | X |
| Notifications | X |
| Global elements | X |
| Monitoring services | X |
| Other external services (chat, widgets,..) | X |

**Learning Flowchart diagram:** See  the diagram on section 3.2.1.

[28] For example, the aural type of learner is provided with the exact some content but it is launched using audio files, the visual type of learner receives images and text. The kinaesthetic type of learner requires different manipulation; it is probable that new material needs to be created from scratch. This has not happened in this UoL.

# Chapter 5 A design methodology for adaptive e-courses influenced by teachers' wisdom of practice

This chapter discusses the proposed design methodology of adaptive e-learning and its contribution as a means of integrating theory, ICT tooling and the practical wisdom of teacher. As already explained in the first chapter of this thesis, this methodology is prescriptive in nature and focuses on how the teacher's Pedagogical Content Knowledge (PCK) has intervened, informed and affected the design choices during the design of an adaptive e-course. The role of the teacher is an essential element of the instructional setting and, as such, its investigation is a valid and meaningful objective of a Design-Based Research study (Gravemeijer and Van Eerde, 2009). The development of a theory in design experiments may emerge at the level of (Gravemeijer & Cobb, 2006):

- the instructional activities (micro theories) or
- the instructional sequence (local instruction theories) or
- the domain-specific instruction theory.

According to Kessels and Korthagen (1996) and Gravemeijer and Cobb (2006), the relations between these levels reflect the distinction between "episteme" and "phronesis." Following Aristotle, they use the Greek word "episteme" to refer to scientific knowledge, and the word "phronesis" to refer to practical wisdom. Also, they stress the importance of research that focuses on the interplay between these two realms.

This chapter discusses how the teacher's "wisdom of practice" can intervene and inform the Technology Enhanced Learning process. My methodology is developed and enacted upon the theoretical frameworks presented in Chapter 3: Simon's Mathematics Teaching Cyle (1995), a domain-specific learning design theory in mathematics and, Shulman's model of pedagogical reasoning and action (1987), a generic model derived from curriculum studies. The products of the intervention are: an adaptive learning strategy and an adaptive e-course in the domain of mathematics. More specifically, a pilot study is described, in which the ensuing adaptive e-learning course was co-designed with a mathematics educator and tested with a small number of students in the school of the participant educator. Also, a roadmap is proposed concerning the stakeholders' involvement, especially the active role of the teacher in the design process. It is based on conceptual mappings between the design-based research steps and the theories used to orientate the research.

In parallel, this chapter aims to justify the refinements in the design of the pilot adaptive e-course and to document and explain the design decisions that I had to take during the refinements. According to Edelson (2002), describing what the researcher has learnt during the iterative design cycles, as well as presenting "lessons learnt", constitutes an essential part of the DBR process. The final products of the pilot testing were: a design methodology, an adaptive learning strategy and an adaptive e-course in the domain of mathematics. The emphasis of the next chapter is on the findings of incorporating the specific adaptive e-learning strategy in the design of a series of adaptive e-courses and then testing its effectiveness with 149 students. The goal of this chapter though is to document how this adaptive e-learning strategy was formed and refined.

## 5.1 Rationale and background

### 5.1.1 Why capturing the "how it came to work"

It has been claimed that the presentation of research results coupled with context-rich descriptions of the design process itself and the decisions made during this process is a good tactic in DBR (McKenney et al., 2006), since it may enhance the generalizability of the findings. This is due to the fact that it might "help the readers to gain insight in what happened during research stages and make inferences based on (or transfer) the findings to other situations" (ibid, p.136). In turn, this enhances the external validity, it makes replications possible and finally enhances the reliability of the research (ibid).

According to Reeves (2006), two general types of contributions within the field of educational design research are "the formulation of education related theories or principles" and "the contribution to an understanding of the design process itself" (p. 151). Regarding the former type, Nieveen et al. (2006), has identified two categories of studies, taking into account their aim in conjunction with the existing learning theories: validation studies, that "aim to (dis)prove existing learning theories" or development studies that "aim to solve an educational problem by using relevant theoretical knowledge" (p. 231). Gravemeijer and Cobb (2006) argue that validation studies may also aim at advancing learning theory and contribute to theory development. Furthermore, they distinguish between micro-theories (that apply at the learning activities level), local instruction theories (that apply at the level of the learning activities sequence) and the domain-specific instruction theory (that apply at the level of pedagogical content knowledge). This thesis revisits Simon's and Shulman's theoretical frameworks on pedagogical content knowledge and seeks to advance them for the scope of adaptive e-learning in order to solve the problem of overcoming the inherent difficulties on the subject matter. Towards, this end the aim of this thesis is not to approve or disapprove but to integrate these models, which were not originally created for adaptive e-learning, in the design process of adaptive eLearning. That is, in this DBR effort, there exist a mutual fine-tuning between the theoretical frameworks (which were not proposed for adaptive e-learning purposes) and the interventions (which integrate them in adaptive e-learning design). Burkhardt (2006) stresses the question from a practical standpoint asking "How far is current theory an adequate basis for design?" In this chapter the design process is not treated as a black-box, since the decisions made during the design are reported and justified .

Gravemeijer and Van Eerde (2009) mention that the cyclic, iterative process of the Simon's Mathematical Teaching cycle bears strong resemblance to the core activity of design research in which teaching instruments are not seen as tests of pre-conceived designs but function as learning situations for researchers. Simon's Mathematics Teaching Cycle is a local instruction theory about a hypothetical learning process for a given topic. Teachers should be supported in this process of designing hypothetical learning trajectories (Gravemeijer and Van Eerde, 2009). In the original Simon's Mathematical Teaching cycle, the learning tasks were "to be adapted to the teacher's goals and teaching style and what is happening in the classroom at a given moment" (ibid, p. 515). In the approach proposed herein the teacher's goals are driven by the need to overcome the inherent difficulties of the topic (a decision taken by me, as the researcher) and, moreover, the tasks do not have to be adapted to what is happening in the classroom at a particular moment, but what is happening in the level of the individual student.

In the context of the research presented herein, like in any other research, design research is carried out within a certain theoretical framework. The theoretical framework impacts how the potential learning goals are framed. In creating a hypothetical learning trajectory and adapting the teaching process, a local instruction theory can be used as a framework of reference (ibid). For the scope of this research, a local instruction theory is indeed used as a framework of reference, in order to design personalised hypothetical learning trajectories.

One of the first preparatory decisions I had to make was to think through learning goals closely in relation to the inherent difficulties of the topic. I came to understand that for some topics they can be elicited by the literature and by guides addressed to teachers (usually by the Ministry of Education), for others they can be elicited by discussing with teachers. I decided that the elicitation of learning goals was to be enabled by using both aforementioned options.

Another step typically included in the preparation phase of a design experiment is specifying assumptions about the student's cognitive starting points. Again, the opinion of the teacher plays a decisive role towards this end. Also, the researcher(s) need to specify assumptions about a) the kind of social norms that may be required in order to facilitate the learning goals (Gravemeijer and Van Eerde, 2009) and b) the role of the teacher and/or of technology in fostering these norms. Wang and Hannafin (2005) mention that, the researcher may need to vary the research methods throughout the interventions as "the focus of the research evolves. Researchers may initially conduct observations to document changes in the classroom environment while using surveys or tests to collect data on student performance" (p. 10). This shift was also the case in my research: from the description of the design process that focuses on how the teacher's Pedagogical Content Knowledge can inform the design process of adaptive learning to testing the proposed adaptive learning strategy i.e. a focus from the design process itself to its outcomes. Also, a shift of the research focus from examining the robustness of the theoretical frameworks that guided the process of co-designing for adaptive e-learning purposes with the teacher to the feasibility of the design solution. The incarnation of the design solution was the series of e-courses that incorporated the proposed adaptive e-learning strategy and the respective interventions in the school classrooms. The proposed adaptive e-learning strategy and the interventions are described in detail in Chapter 6. As previously mentioned, Chapter 6 generalises on Chapter 5, since this chapter discusses how the adaptive e-learning strategy was formed during a pilot study that took place in two iterative cycles of design and refinement, while Chapter 6 discusses what happened in the third iterative cycle.

That is, this chapter focuses on the first part, i.e. the one before the methodological shift. It discusses the design process while putting emphasis on the active role of the teacher in designing adaptive e-courses. In doing so, the theoretical frameworks mentioned in Chapter 3 were exploited. Methodologically speaking, mixed methods were used: screen recording software and video analysis (as a method of computer supported classroom observation), focus group with the participant students and a post-test taken by the participant students at the end of the second iterative cycle of the pilot study,  asdescribed in the next sections.

### 5.1.2 Didactics and pedagogy integrated in the e-course design of the pilot phase

According to studies in the didactics of mathematics, the concepts of ratio and proportions present difficulties for the students (Singh, 2000). It has been argued that, in their attempts to solve problems related to these two concepts, the students use low level cognitive strategies based upon additive reasoning, as opposed to higher-order cognitive strategies that utilize multiplicative reasoning (Lamon,1993; Noelting,1980). Also, students have the tendency to treat pseudo-proportionality problems as if they were actual proportionality problems and, consequently, they apply linear models to them (Modestou & Gagatsis, 2007). A classic example of a pseudo-proportionality problem -created by Markovitz et al. (1984) mentioned in (Verschaffel et al, 2000)- is the following : “If the height of a ten-years-old boy is one meter and 40 centimeters, then how tall will he be when he will reach the age of 20 years?”.

Regarding the additive reasoning, this problem exemplifies it: “Andrew decided to paint his room on his own, so he made the mix of the colours by himself in order to make a specific tone of blue colour. Thus, he mixed six liters blue paint with nine liters of white paint. But the quantity of paint was not enough and so, he made a new mixture in which he mixed four liters of blue paint with seven liters of white paint. Did he succeed in making the exact tone of blue as the initial one?”

Pedagogically speaking, the design of this adaptive e-course adheres to Resource-Based Learning (RBL). RBL establishes meaning making as opposed to the mere consumption of the learning content through the process (Hill & Hannafin, 2001): data, then information, then knowledge and finally, meaning. Key considerations in this process are: contexts, tool, scaffolds and resources. Examples of RBL in conjunction with the VARK learning taxonomy include the following:

- For the visual type of learner: students are presented with a photograph taken outside their school and they were asked to calculate the actual height of a tree (in meters) provided that they had a ruler in their disposal.
- For the aural type of learner: students were strongly encouraged to discuss their understandings with their peers and come up together with a solution to the problem.
- For the Read/write type of learner: students used a collaborative authoring tool to report their ideas and reflect on the ideas of their peers. For this purpose, an e-noticeboard application was used (namely, "padlet").
- For the kinesthetic type of learner: students used a pedometer in the form of a built-in app in a ipad in order to calculate the ratio (numbers of steps taken)/(time needed) and compared their ratio with the ratio of their peers in order to opine whether they walk with the same speed.

## 5. 2 The technical characteristics of the adaptive e-course

The adaptive e-course designed in the pilot phase which is described in this chapter, as well as, the other e-courses that were developed in the third iterative cycle of the Design-Based Research endeavour (described in the next chapter) were created using the ReCourse Learning Design Editor. It is an IMS-LD (level C) compliant tool, which was developed as part of the European-funded TENCompetence project. I selected this specific tool because it is considered a second generation IMS-LD compliant tool, which, compared to the first generation, provides a better graphical user interface that combines form-based and graphical-based authoring of Learning Designs[29] and Learning Design templates (Sampson & Zervas, 2011). In addition, it is a freeware, open source software. Also, it supports the creation of "rich" adaptive learning designs, in which more than one adaptation parameters can be combined within more than one

[29] The terms "Learning Design" and "Unit of Learning" are used interchangeably in this chapter.

adaptation methods in non-predefined ways, leaving all the design decisions up to the designers. Yet, as discussed in the previous chapter, this freedom doesn't come without a price, since technical knowledge and programming knowledge is required on behalf of the course developer. Also, the embedded adaptation logic is rule-based, in the form of IF…THEN…ELSE… production rules. As already discussed, the course diagram of an adaptive Learning Design is a collection of Finite State Machines (FSMs). The Learning Design can be uploaded in an IMS-LD player which initialises the production rules that provides the adaptivity Also, it provides a preview of the Learning Design. From my experience regarding the creation of adaptive e-courses, the number of production rules needed to implement an adaptive e-learning strategy significantly increases as the adaptivity complexity increases (the levels of adaptivity complexity were described in section 2.10). As already mentioned, the IMS-LD player is also an open source software (mostly written in Java). I configured it as web service which, during the interventions, was publicly available online. The online service was hosted under the domain name of the Open University of Cyprus.

In order to create the different versions of the same learning resource, so as to enable the adaptive content presentation method in which the input parameter is the learning style preference (for example, the same learning resource, with or without audio narrative) I had to intervene in the XHTML code of the corresponding task webpage. The adaptive content presentation was technically feasible through the use of 'div classes' in XHMTL documents that show or hide elements (like an audio recording or an image) on a conditional basis, as originally suggested by Burgos et. al, (2006) and Santos et al (2008).

## 5.3 Methodology

### 5.3.1 Instruments

In both rounds screen recording was used as an audiovisual method for classroom observation. Each round lasted for a two-classroom periods i.e. for 80 minutes. Both the researcher and the teacher supported the intervention and provided assistance whenever a technical matter occurred (for example, a pop up window appeared in the desktop). After the second iterative cycle I conducted a ten-minutes duration focus group discussion with the participant students in order to understand to what extend they liked the e-course. I recorded the discussion I had with the students using the Camtasia software.

In order to conclude on the learning style preference of the participant students, the VARK learning style questionnaire was administered to the students before the beginning of the interventions. In order to conclude on their learning progress, a post-test was administered to the students eight weeks after the intervention. The post-test contained two problems, one for each of the inherent difficulties of the topic that we had identified (e.g. pseudo-proportionality and additive reasoning). The students were asked to devote to the problems of the post-test no more than 15 minutes for both problems. The students and the parents were not informed about the post-test beforehand, because I wanted to exclude the possibility of studying at home, since that would be a confounding variable. Seven students from the focus group (students from the second iterative cycle) agreed to participate and, consequently, seven students as a control group were also selected. The two groups were matched, in the sense that they were alike in their mathematical ability, as measured by their oral and written performance in mathematics throughout the school year. (The second iterative cycle took place near the end of the school year 2012-2013). The results of the post-tests were scored by two external mathematics educators. The post-tests were anonymized before being handed out to the external evaluators.

### 5.3.2 Issues related to screen recording and video analysis

The purpose of the screen recording software was threefold: a) to confirm that students are indeed making frequent errors related to pseudo-proportionality and the use of additive reasoning and provide insight on how to turn the difficulties of the subject matter into opportunities of learning from errors, b) to assess the extent in which a student with a diagnosed strong learning style preference would be satisfied by receiving media according to her preference alone, c) to shed light on how response-specific computerized adaptive feedback could be incorporated in the adaptive e-course. I conducted that video analysis which revolved around the aforementioned issues. That is, while viewing the videos, I tried to identify points in the recordings where one or more out of the issues (a) to (c) emerged.

With regards to privacy issues and how the video recordings data were to be used in the context of my research, several protective measures were taken to give participants control over the collection and the usage of the raw data: a) only the researcher was to have access to the recorded data and b) the recorded data were to be held and analysed only by the researcher for the sole purposes of this research. In addition to these rules, the general rules about confidentiality and anonymity (mentioned in the last chapter) apply. These additional rules were needed in order to compensate for the fact that screen recording generated replicas of what participants did, saw and discussed, as well as their facial expressions and gestures. This might have provoked a feeling of uneasiness to the participants, be perceived as invasive by them and/or make them feel uncomfortable.

In terms of data portability, current video compression algorithms reduced one hour of screen recording with rate of 30 frames/second to a file size of approximately one gigabyte. Thus, a portable mass storage devices (e.g. an external hard drive) was needed to conveniently collect these data from the classroom for analysis. The fact that audio was also recorded almost doubled the amount of digital data generated and increased the privacy concerns for the participants. On the other hand, audio recording clarifies what is actually being recorded (Tang et al., 2006). In total, almost 9 hours of recording were collected, which resulted into 10.745 gigabytes of data. Concerning the refinements of the designed artefact, participants' observation was exploited in conjunction with screen- and video-capturing using the Camtasia® recording software. The discussions with the teacher and the reflections derived from the recordings provided insights on the design of the adaptive e-course.

### 5.3.3 Shaping the adaptive e-learning strategy

The proposed e-learning strategy takes into account:

- That students facing authentic problems (Dooren et al., 2007) are more likely to abandon the stereotypical, "mechanical" way of solving the problem and engage in a meaningful problem-solving behavior.
- The affordances of adaptive and personalized learning that correspond to the student's characteristics. The adaptation parameters that intervene in the design were derived from

the preliminary research stage. These are: student (prior) knowledge, the student performance in conjunction with the learning goals (which are driven by the inherent difficulties of the subject matter) and the student learning preference. In particular, with regards to the latter, the VARK taxonomy is used (Fleming & Baume, 2006; Leite et al, 2010). The justification for the selection of this specific taxonomy is provided in the preliminary research chapter.

Based on these factors, the learning activities and their sequencing are differentiated, that is, each student traverses a potentially different learning path. Also, based on the learning preference of the student, the presentation of the content is differentiated, that is, the same content is presented through an image or a diagram to the visual type, through a narration to the aural type, the "read-write" type will read it through a text format etc. A more detailed description of this specific mapping methodology can be found in the preliminary research chapter.

Other elements incorporated in this course are: the provision of adaptive feedback and the opportunity of learning from errors. When a student makes an error in a question that examines her prior knowledge in the diagnostic phase or in the problems she encounters later, the error is detected and remedial actions are triggered. The aim is to provoke the destabilization of the student's alternative conception or providing support with the specific difficulty of the subject matter that the student tries to overcome.

## 5.4 Application of the methodology proposed in the setting of the intervention

<u>Orientation/First steps:</u> The key considerations of this phase and the ensuing outcomes are already described in the previous section (section 5.4.2), as well as, in the preliminary research chapter. They involve the selection of: the adaptation parameters, the adaptation methods, and the learning style taxonomy. The main aim of this phase is to orientate the adaptive elearning strategy close to the teachers' views from the beginning of the design.

<u>Problem statement and consultation with practitioners:</u> Next, I discussed with the specific teacher who participated in the intervention on the analogies course the possibilities for creating an adaptive e-course about this topic. I explained the adaptive elearning strategy and discussed with the teacher about the learning style aspect and how it might be related to the content

transformation- see previous chapter. After the discussion, the teacher informed the principal of the school in order to obtain an initial approval, since the stakeholders' involvement is crucial in the DBR process (Walker, 2006). Following, I wrote a report with the research plan which was sent to the "Centre of Educational Research and Evaluation (CERE)" (http://goo.gl/TVSpkG ). CERE is an Institution which is under the auspices of the Ministry of Education of Cyprus aiming to promote and support research at the school level.

Development of  solutions informed by existing design principles and technological innovations: It was decided that the educational problem at stake could be meaningful pedagogically if the learning objectives focused on the inherent difficulties of the subject matter. Following, I conducted a literature review which led to the selection of the specific mathematics topic (i.e. analogies and proportions) as a subject matter for which clear and plenty evidence exist in the literature that converge on specific difficulties. Also, Shulman's model of Pedagogical Reasoning and Action and Simon's mathematical teaching cycle were selected as components of a theoretical framework that shed light on how to cope with the adaptation issue. At that point of the methodology, I consulted the teacher's comprehension on the core concepts, the structures and the learning difficulties of the subject matter. With regards to the learning difficulties, they were confirmed by the teacher.

Next, the prerequisite knowledge, the identification of the learning goals, the hypothetical Learning Trajectory and the transformations of the content were discussed with the teacher. Towards this end, the mappings between the learning style preference and the media characteristics played a decisive role. I created and uploaded online (using the IMS-LD player service) the initial prototype adaptive e-course. Two consecutive cycles of design and enactment in classroom settings took place, resulting at the refinement of the final solution.

Iterative cycles of testing & refinement of solutions in practice: An elapsed time of a month was devoted between the two cycles in order to make the needed refinements of the initial design. The main refinement after the first cycle was related to the use of media elements in accordance with the learning style. From the participants' observation it became evident that, in some cases where students were diagnosed as having a single-preference, alternative media were needed in addition to those supposedly preferred.  The refinements made after the second cycle involved aspects of adaptive feedback and remedial actions. Based on classroom observations, the need for more elaborative, topic-related and immediate computerised feedback emerged.

## 5.5 Implications: the design methodology

Table 6 generalizes the methodology described above and illustrates the conceptual mappings between the phases of: DBR enactment as mentioned in (Herrington et al, 2012), the Simon's mathematical teaching cycle and Shulman's model of pedagogical reasoning and action. Understandably, the two theories have common elements and overlapping phases, like: discuss teaching/discuss instruction, discuss about the assessment of students' understandings/ discuss about evaluation of performance and others.  This methodology exemplifies:

- design pathways for adaptive learning in mathematics, through the mappings between the phases of the DBR process and Simon's mathematical teaching cycle, and,
- design pathways for adaptive learning in general, through the mappings between the phases of the DBR process and Shulman's model

For example, in the analysis phase, I consulted the teacher's comprehension about the subject matter. This interaction affected and was affected by the problem statement, the research questions and the related literature, and so on for the next phases.

**Table 7 The conceptual mappings between DBR and the theoretical frameworks**

| Phases of DBR process | Topics/Elements | Phases of Simon's mathematical teaching cycle | Phases of Shulman's model of Pedagogical Reasoning and Action |
|---|---|---|---|
| Analysis of practical problems by researchers and practitioners in | Problem statement<br>Consultation with practitioners<br>Research | Consult teacher's comprehension | |

| | | | |
|---|---|---|---|
| collaboration | questions<br>Literature review | | |
| Development of solutions informed by existing design principles and technological innovations | Theoretical framework<br>Development of draft principles to guide the design<br>Description of the proposed intervention | Discuss about:<br>-Assessment of student's prior knowledge<br>-Identification of the learning goals<br>-Hypothetical Learning Trajectory<br>-Planning & design of proper learning activities | Discuss about<br>and access content transformations,<br>and alternative representations |
| Iterative cycles of<br>testing & refinement of solutions in practice | Input for improvement of the intervention | -Observe teaching<br>- Discuss about the assessment of students' understandings | - Observe<br>instruction<br>-Discuss about evaluation of performance |
| Reflection to produce<br>"design principles" and enhance solution | -Design principles<br>-Designed artifacts<br>-Professional | -Discuss about next iteration | - Articulate<br>reflections<br>- Understand the new comprehensions |

implementation development

Digital resources were incorporated on the ground that a roadmap from the mere use of data to meaning making can be fostered while focusing on the inherent difficulties of the topic, as described above. These inherent difficulties apply universally, while: a) alignment of the curricula across Europe is incomplete and b) adaptive learning and remediation technologies are included among the challenges of the EC agenda. Consequently, this methodology can serve as a means of discussion and collaboration between school teachers, university tutors and researchers in a European-wide level, for example, through (online) communities of practice.

## 5.6 Preliminary results of the pilot study

The analysis contains two independent samples t-tests (between the focus group and the control group): one for the students' general mathematical ability and one for their performance in the post-test. In the table 8 below, the t-test for the former is shown, whereas the results of the table 9 correspond to the latter issue.

**Table 8 Group statistics on mathematical ability**

| | Group | N | Mean | Std. Deviation |
|---|---|---|---|---|
| mathematical ability | Focus group | 7 | 13.29 | 4.572 |
| | Control group | 7 | 10.71 | 3.200 |

There was homogeneity of variances for engagement scores, as assessed by Levene's test for equality of variances ($p = .122$). The t-test revealed that this difference (13.29 out of 20 in the focus group and 10.71 out of 20 in the control group) of the students' performance in mathematics was not significant, $t(12) = 0.246$.

Table 9 Group statistics on test performance

| | Group | N | Mean | Std. Deviation |
|---|---|---|---|---|
| performance | Focus group | 7 | 7.14 | 4.880 |
| | Control group | 7 | 2.86 | 4.880 |

As depicted from the table above, the mean score performance of the focus group was equal to 7.14 (out of 10) while in the control group it was equal to 2.86 (out of 10). At that point (end of the second cycle), where the design intervention was still considered a work-in-progress, this was an encouraging indicator to continue with the design and further enhance it, although the size of the sample was small. Another encouraging indicator was the acceptance of the e-course on behalf of the students that participated in this pilot study, as it was revealed by reflecting on the audio recording of the focus group discussion.

## 5.7 Conclusions & lessons learnt

In this chapter, a methodological framework that embraces close collaboration with the teacher is proposed, but it is acknowledged that this supposition constitutes both a strength and limitation, since although continuous and close researcher-teacher collaboration would be ideal, oftentimes this is not possible. Although the between-pairs collaboration worked well and provided useful insights on what the students were thinking while trying to solve the problems they encountered, it wasn't used in the next stage of the research since, as already discussed, the third iterative cycle involves a methodological shift to a Randomised Control Trial (RCT) with a large number of students where the effectiveness of collaboration would be an extra parameter that would bring "noise" in the RCT which I was afraid that I could not handle. Regarding feedback, the qualitative methods used in the first two cycles provided valuable insights on how computerised feedback could be an effective alternative. More details about the provision of response-specific computerised feedback are described in the next chapter.

The approach discussed herein resembles Constraint-Based Modelling (CBM)(Ohlsson, 1996; Mitrovic et al., 2003). Similar to the approach adopted in this thesis, CBM promotes the idea of learning from errors (error detection and error recognition) and aims to simplify the student model by focusing on students' misconceptions. Another similarity with CBM is that it seeks to careful design sequences of feedback messages in order to mimic the action of a human teacher in helping the student to overcome his/her misconceptions. Unlike to CBM though, my theoretical framework is not the ACT-R theory of cognition.

Finally, regarding lessons learnt related to how teachers as designers can be better understood: before the design of the adaptive e-course diagram by the teacher, she or he needed to provide or to suggest resources based on the proposed conceptual mappings-chapter 4. It was suprising that oftentimes, the teacher was hesitant or reluctant to add a specific learning resource to the pool of learning resources that were to be integrated in the adaptive e-course because they were afraid that the learning resource or learning activity could be too difficult for their students. And if that happened, then a new discussion had to begin in order to make the teacher realise that, in the context of an adaptive eLearning course, the relative (to the 'average' student) difficulty of the learning activity is not a crucial factor because in case the student fails to successfully complete the particular learning activity, he or she will be prompted with another learning activity that could be easier but it will still revolve around the same learning topic.  Thus, the discussions with the teachers during the design process of the adaptive e-courses, helped the teacher change their way of thinking in conjunction to personalized learning in tandem with the use of technology and better realise the meaning and potentials of adaptive eLearning.

## 5.8 Annexes

**Discussion protocol**

In the context of this work you will be the co-designer of adaptive e-courses. Adaptive learning is an umbrella term that describes the techniques used by computer-based learning environments that attempt to mimic what a teacher would do in a learning situation provided that each student has different learning needs. The purpose here is to integrate in the creation of an adaptive elearning course the practical wisdom of the teacher.

- What is the chosen topic?

- What are the associated concepts?

- What is the purpose of teaching it?

In the context of this work the inherent difficulties are closely related to the associated learning objectives; and the purpose of teaching it is to help students overcome the inherent difficulties of the subject matter. The inherent difficulties are those that students find difficult to teach or teachers find difficult to teach. For example, you know that in the identities lesson a portion of students will mistakenly think that (a + b)2 = a2 + b2. This lesson is so common among students worldwide that has even received a name: freshman's dream. You can search it in the Wikipedia. Its general form is: ( a + b)n = an + bn.

So, what are the inherent difficulties of the selected topic?

- In this work we will use resources and learning activities that match students' learning preference. To this end we will use the VARK model. VARK is an abbreviation for Visual-Auditory-Read/Write-Kinesthetic and multimodal type of learners.

(Then I explain to the teacher the proposed mappings between the learning style preference and the characteristics of learning activity or media – Chapter 4 and I provide examples.)

We need to create a pool of resources that serve this purpose. Could you please provide or suggest suitable resources or learning activities?

- We need to create the course design of the adaptive e-course and the hypothetical learning paths. This is an example. (Then I showed to the teacher the figure taken from (Mousley et al, 2004) and a completed example of a course diagram depicting the alternative trajectories of an adaptive e-course).

Can you create the alternative trajectories taking into account that this course will provide response-contingent or bug-related feedback? (I explain to the teacher why this is needed and when the feedback is response-contingent or bug-related. While doing that, I describe the completed course diagram for the adaptive e-course as an example to help the teacher visualize her thoughts.

## Lesson diagrams

The below lesson diagrams were created by the participant teachers (one diagram per lesson). They constitue the output of the researcher-teacher co-operation using the discussion protocol presented in the previous annex.

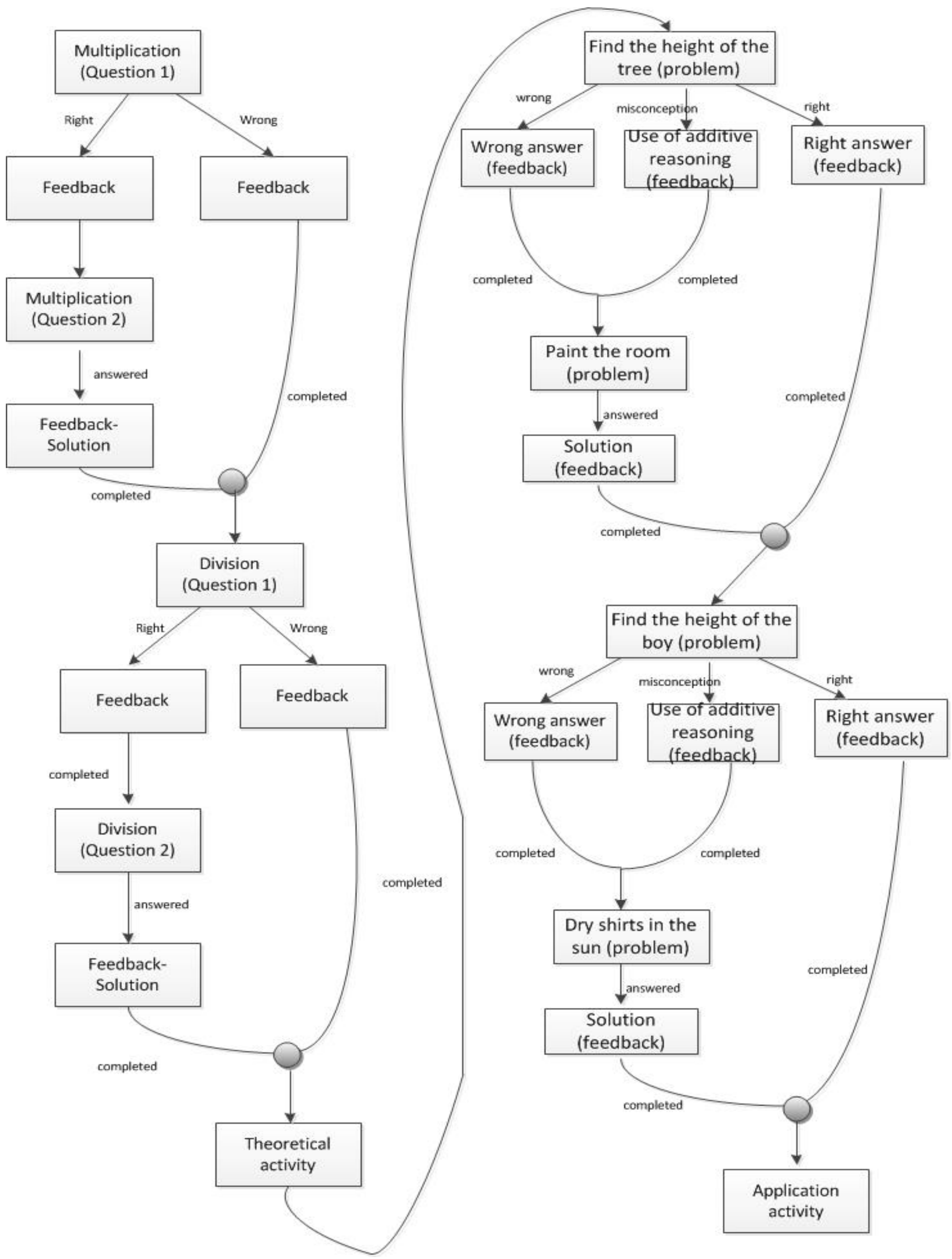



Figure 19 Lesson diagram 1: Ratios and Analogies

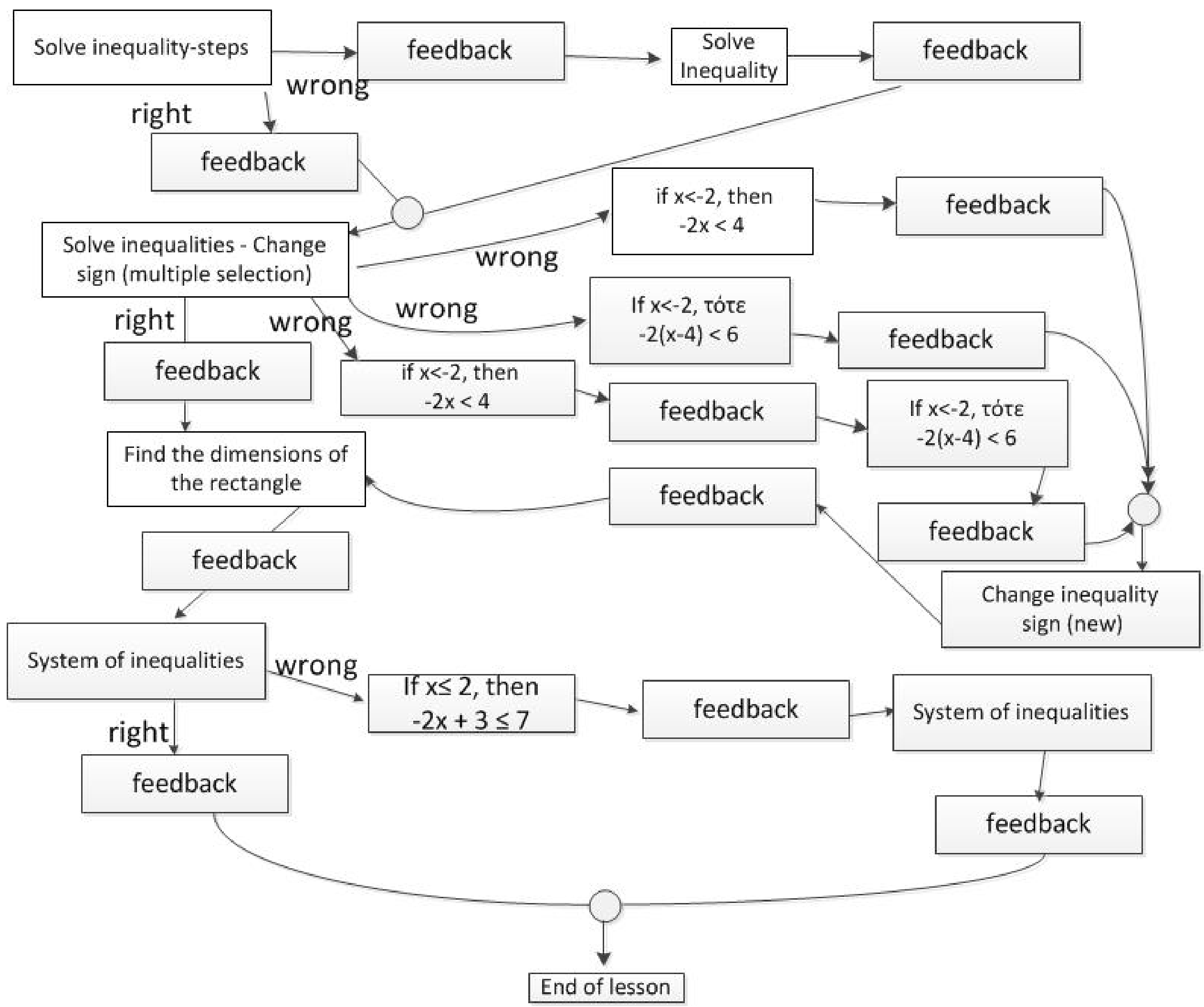



**Figure 20 Lesson diagram 2: Inequalities**

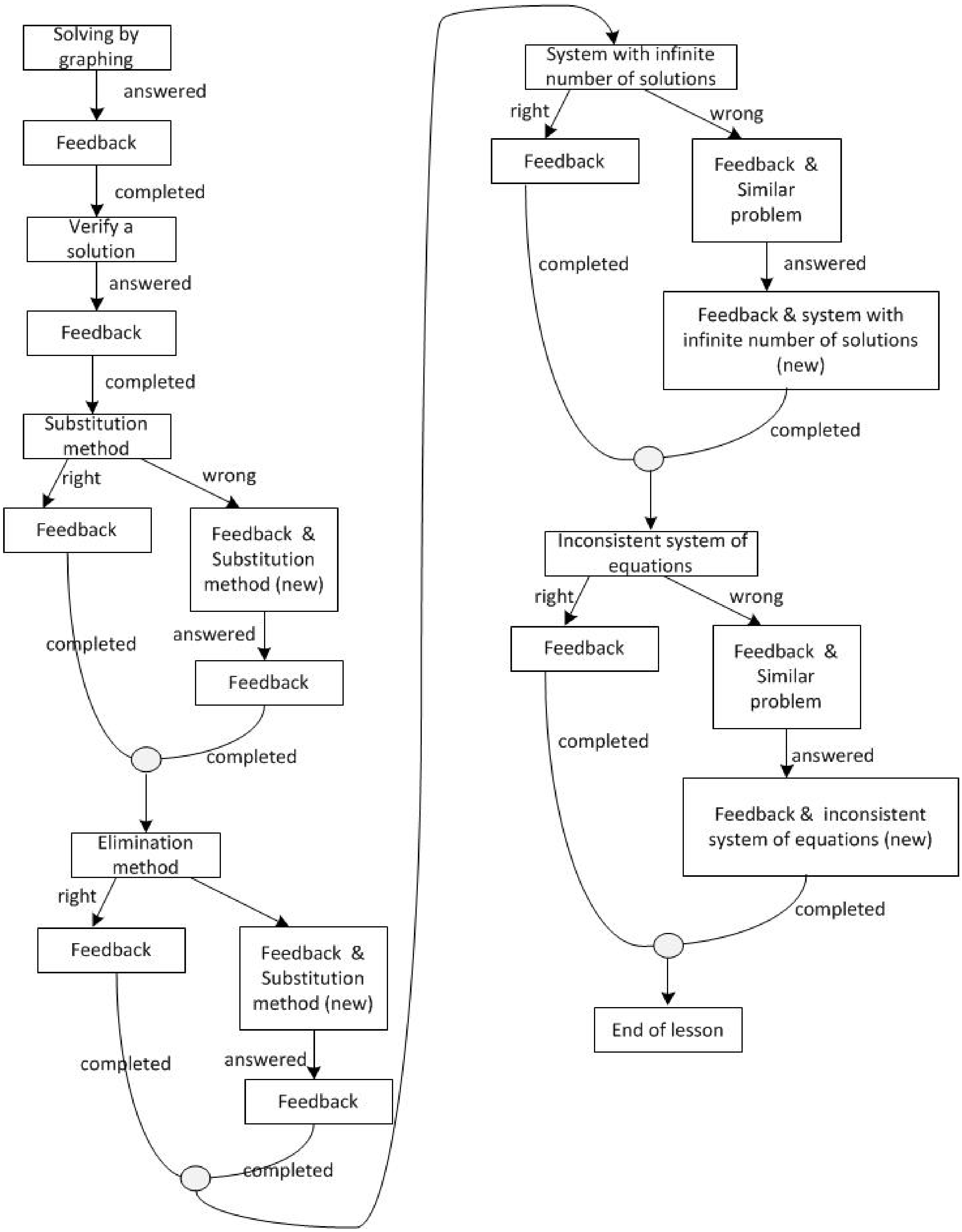



Figure 21 Lesson diagram 3: System of linear equations

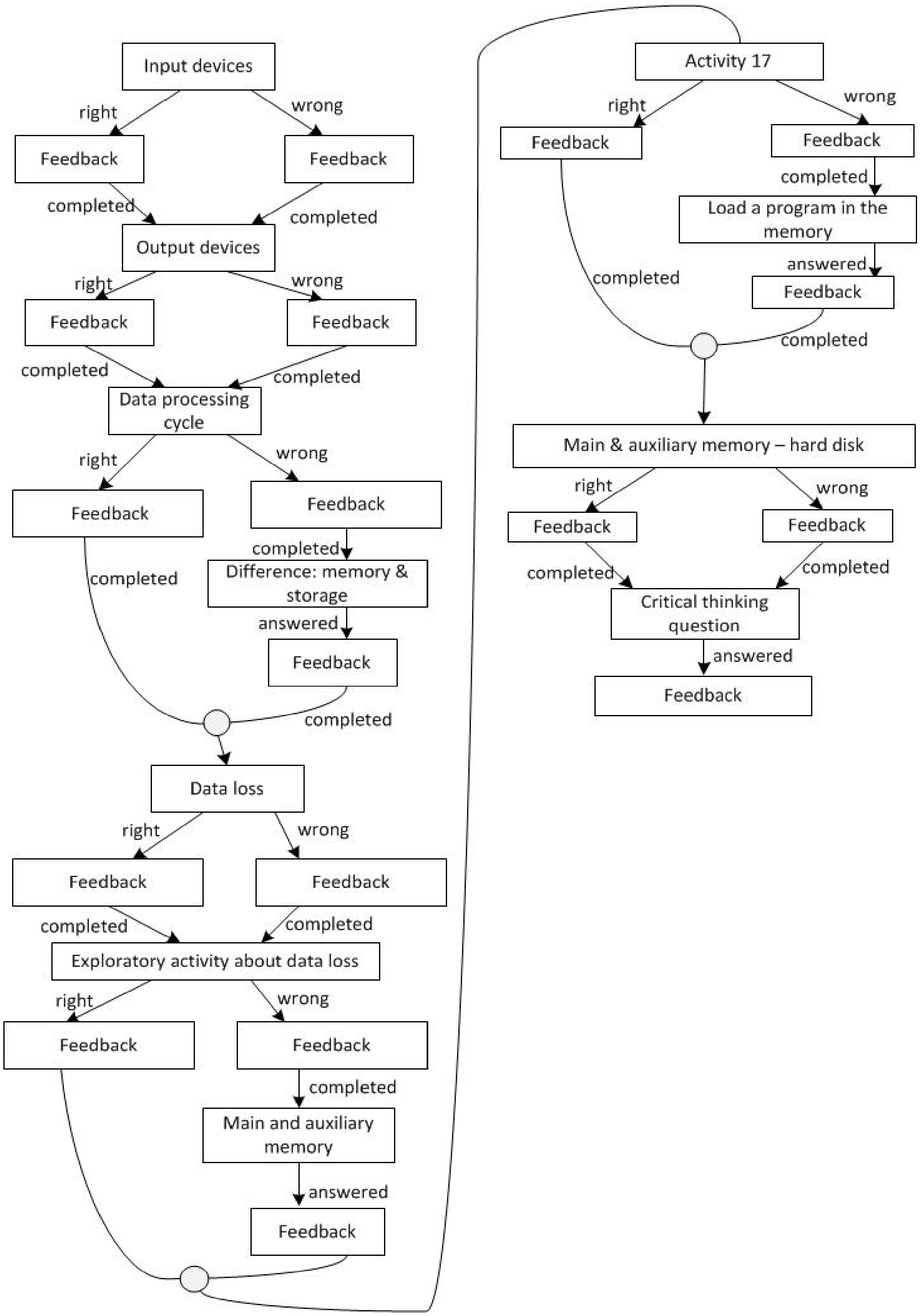



Figure 22 Lesson diagram 4: Main and auxiliary memory

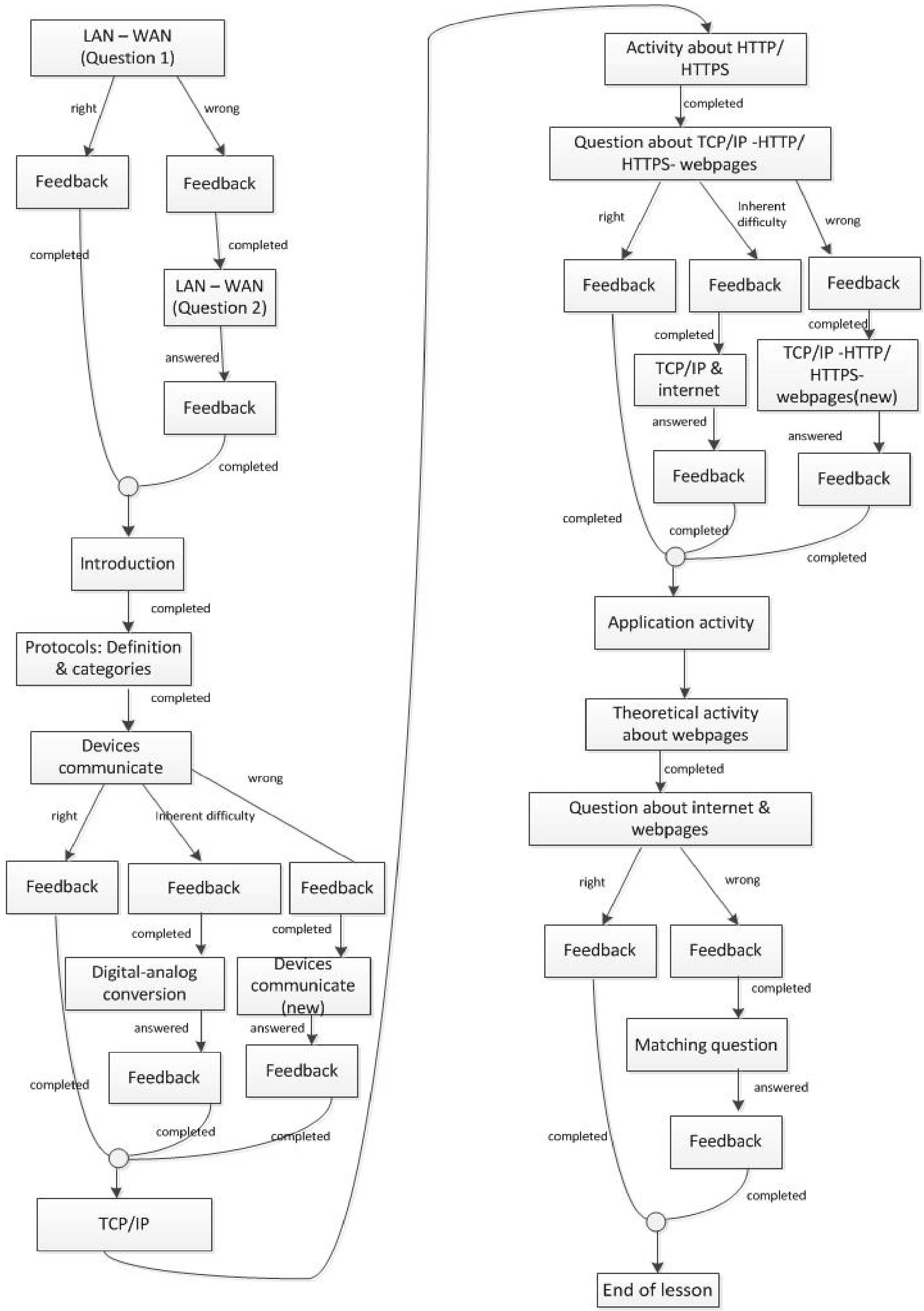



**Figure 23 Lesson diagram 5: Communication Protocols**

**Classroom observation protocol**

Number of students:

Date:

Class:

| Time | Teacher-student interaction | Students' interaction | Students' computer screen | Comments |
|---|---|---|---|---|
| | | | | |
| | | | | |

# Chapter 6 A design theory for adaptive eLearning on STEM

This chapter generalises on the findings of the previous chapter which described how the adaptive e-learning strategy was originally formed as well as some preliminary results on its effectiveness during a pilot study. In the context of DBR, it is useful and productive to conduct mini randomized trials at choice points (Kelly, 2006). This point in my study was the end of the second consecutive cycle of the DBR process. This chapter reports on the empirical findings of five interventions that were undertaken to investigate the impact of the proposed strategy during the third iterative cycle. For each intervention, I co-designed an adaptive e-course with a teacher using the methodology and the adaptive e-learning strategy mentioned in the previous chapter. The effectiveness of the adaptive e-courses was tested with the students of the participant teachers in their classrooms, with encouraging results. The work discussed in this chapter can be used as the basis for future studies that validate the adaptive e-learning strategy with other subject matters than those mentioned herein (which involve the STEM domain).

The Instructional Design for both the adaptive and the non-adaptive e-courses aimed at helping students overcome the inherent difficulties of the topic. Thus, the content and its representations, as well as, the learning activities incorporated in the e-courses were aligned with this broader goal. This is also true for their structure. For example, at the beginning of both the adaptive and the non-adaptive e-courses, a preparatory phase was included aiming to help students recall prior knowledge. Yet, in the adaptive e-courses the structure of activities (i.e. the number of learning activities and the learning flow) was additionally influenced by the adaptive eLearning philosophy. Similarly, in the case of adaptive e-courses, the content representation was additionally influenced by the need to personalize the representation of the learning content to the students' learning preference. Finally, as already discussed in the previous chapter, the adaptive e-courses were aligned with the Resource-Based Learning (RBL) approach that facilitates meaning-making processes by providing tools, scaffolds, recourses and contexts. In the adaptive e-courses, this provision was synced with the student's profile and took place in as-needed basis. In the non-adaptive e-courses, the use of RBL was not synced with the student's profile; for example, all students following non-adaptive e-courses received the same scaffolds, the same resources etc.

## 6.1 Background

### 6.1.1 Connections with previous chapters

As previously discussed, teachers persistently and intentionally adapt their instruction without formal knowledge of individual differences, and without objectively assessing them (Randi & Corno, 2005). Teachers' designing instruction develops the capacity to adapt (idib). Effective scaffolding (i.e. providing supportive assistance to students when they need it) depends on the teacher's capability to concurrently assess and respond to students' learning needs (Randi & Corno, 2005). As mentioned in Chapter 2, Shulman (1986, 1987) in his seminal work discussed the idea of adaptation interweaved with the concept of teacher's pedagogical content knowledge into a model of pedagogical reasoning and action. My preliminary research (Chapter 4) showed that teachers adapt their lessons based on parameters like prior knowledge, learning style or preference, learning strategy, learning objectives, while taking into account practical restrictions, like time availability. Concerning the learning preference parameter, in this study, a preliminary strategy for adaptive e-learning was proposed in Chapter 4. It is based on mappings between learning preferences, where the learning preference is in line with the VARK (Visual, Auditory, Read/write, Kinesthetic and multimodal) model, with types of learning activities and media types. The selection of this specific taxonomy is in line with the "teachers as designers" philosophy (McKenney et al., 2012; Carlgren, 1999; Shamir-Inbal & Kali, 2009; Mor & Mogilevsky, 2013) that traverses the whole research design. Unfortunately, in the adaptive e-learning area, engaging the teachers still remains a challenge (Katsamani et al., 2012). Yet, it seems that the VARK learning style model can offer commonsense descriptions of students' learning preferences to the teachers with which the teachers can associate their teaching practices more effectively compared to other learning or cognitive style models (see Chapter 4).

From a methodological perspective, my research "pays greater attention to advances in mixed methods and more expansive views of randomized field trials" (Kelly, 2006, p. 177), as well as to workflows through multiple cycles, where the earlier cycles exploit exploratory research methods like observation, identification of variables/processes, modeling, prototyping and the later stages emphasize confirmatory research methods (Nieveen et al, 2006). As Nieveen suggests, "the exploratory emphasis is necessary to arrive at well-designed innovations, worthy of going to scale; and the confirmatory emphasis is necessary not only to test the impact of an innovation, but also to provide sound inputs for future exploratory work" (ibid). This methodological approach is also adopted in this study: Chapter 5 has an exploratory emphasis, whereas this chapter adopts a confirmatory point of view. Chapter 8 concludes with future exploratory work based on the work described in this chapter.

### 6.1.2 Interest in the aspects of motivation, age and prior knowledge

Student motivation is a key variable in education. For example, it has been suggested that motivation, learning styles, and student performance are linked (Shih & Gamon, 2001; Curry, 1990). Examples of motivation studies include the study of Tuan et al. (2005) who developed a questionnaire that measures student motivation towards science learning and the study of Berger & Karabenick (2010) who developed a questionnaire used to measure student motivation specifically for mathematics. The latter is being used in this chapter. More details about it will be presented in the methodology section below.

With regards to students age, the whole idea of distinguishing between adult learning (andragogy) field and the cognitive child development field is based on the premise that student age is an important variable in education. For example, according to Piaget's Cognitive Theory (1970) students aged more than 11 years old enter the formal operational stage in which they start to exploit qualities like creativity, abstract reasoning, inferential reasoning etc in the problem solving process. On the other hand, the theory also focuses on individual differences, thus it can be inferred that some children aged 12 years old may not be as competent in conjunction with the above qualities. Provided that the students that participate in this research are 12 to 16 years old, studying any relationship between student performance and age is a valid act.

Finally, with regards to student prior knowledge, it is commonly accepted that its activation can provoke meaningful learning (see for example Merrill, 2002). Roschelle (1997) explicitly mentions that "neglect of prior knowledge can result in the audience learning something opposed to the educator's intentions, no matter how well those intentions are executed in an exhibit, book, or lecture." (p.40)

## 6.2 Methodology and instruments

### 6.2.1 The adaptive e- courses

A series of adaptive e-courses were designed, developed, implemented, and tested in real classroom settings. Five learning topics were selected from the STEM (Science, Technology, Engineering, Mathematics) domain and in particular, Mathematics and Informatics. A literature review revealed clear evidence, which converges on specific inherent difficulties, i.e., common student errors or topics that present difficulties for the students to understand or for the teachers to teach (Angeli & Valanides, 2005).

Accordingly, five adaptive e-courses that focused on inherent topic difficulties were designed and developed. The table below outlines: the topics of the e-courses, the respective domains and the difficulties that each subject matter presents. The design was participatory in the sense that I, as the designer of the e-courses, frequently consulted teachers' comprehension on the core concepts, the structure and the learning difficulties of the subject matter. At the beginning of the e-courses design, the participant teachers confirmed the difficulties mentioned in the table below.

**Table 10 Inherent difficulties in each topic**

| Topic/ domain | Difficulties |
|---|---|
| Inequalities/ Mathematics | 1. Students reject solutions that do not fit the general pattern, i.e., an interval for inequalities, a unique value for equations (Tsamir & Bazzini, 2001).<br>2. Students multiply or divide the two sides of an inequality by the same number without checking whether the number is positive, negative, or zero (Bazzini & Tsamir, 2004; Halmaghi, 2010). |
| Ratios and | 1. Students have the tendency to treat pseudo- |

| | |
|---|---|
| analogies/ Mathematics | proportionality problems as if they were actual proportionality problems, and, consequently, they apply linear models to them (Modestou & Gagatsis, 2007).<br>2. Students use additive reasoning instead of multiplicative in proportionality problems (Lamon, 1993). |
| System of linear equations/ Mathematics | 1. Students are facing difficulties in understanding that different representations of a system (graph, algebraic solution, ordered values table) are equivalent, and move back and forth between them (Proulx et al., 2009).<br>2. Students are not sure what to do when all variables are eliminated, or when the system doesn't have a solution (Proulx et al., 2009). |
| WWW, Internet and communication protocols/ Informatics | 1. It is difficult to teach how two different digital devices communicate (Ioannou & Angeli, 2013).<br>2. Students do not differentiate between Internet and WWW (Ioannou & Angeli, 2013). |
| Main and auxiliary memory/ Informatics | There is a complexity in explaining the differences between the two types of memory (Ioannou & Angeli, 2013). |

The five interventions followed the randomized control pretest-posttest experimental design paradigm. In each of the interventions, an adaptive learning e-course was enacted to the experimental group, whereas a non-adaptive e-course was implemented to the control group. Common characteristics of each e-course in both student groups (experimental and control) were the following: (a) focus on the inherent difficulties of the topic to be taught/learned; b) inclusion of a preparatory phase at the beginning of the e-course aiming to help students recall prior knowledge, and (c) incorporation of a wide range of different content representations.

The courses offered for the control group had a linear/sequential learning flow in tandem with knowledge-of-response type of feedback and elaborative feedback as well (Mason & Bruning, 2001; Gouli, Gogoulou, Papanikolaou & Grigoriadou, 2006). Knowledge-of-correct-response supplied learners with the correct answer, while elaborative feedback explained why the specific answer was the correct one. Accordingly, the courses of the experimental group had one or both of the following design attributes:

- Non-linear/networked learning flow in tandem with bug-related adaptive feedback (Mason & Bruning, 2001; Gouli et al, 2006). Response-contingent feedback provided knowledge of the correct response along with an explanation of why the incorrect answer was wrong and why the correct answer is correct. Then, in case of an incorrect answer, the student was presented with a similar problem. For example, if the student had answered "2 meters and 8 centimeters" in the classical pseudo-proportionality problem (Markovitz et al., 1984): "If the height of a ten-years-old boy is one meter and 40 centimeters, then how tall will he be when he will reach the age of 20 years?", then, the student received response-contingent feedback, which was related to the pseudo-proportionality focusing on the connection of mathematics with the real world. Next, another pseudo-proportionality problem was presented to the student. The second problem was treated with knowledge-of-response type of feedback in tandem with elaborative feedback, as it was the case with the control group. Bug-related feedback provides item verification (was the answer correct?) along with scaffolds to help them identify procedural errors, so that self-correction is possible (Mason & Bruning, 2001). For example, changing the sense of an equality when the coefficient is negative. Then, after the bug-related feedback, students were presented again with the original problem. After their second attempt to answer, students received knowledge-of-response in tandem with elaborative feedback, as it was the case with the control group.

- Media in accordance to students' diagnosed learning styles (see strategy suggested in Chapter 4). Towards this end, the VARK model (Fleming, 2001) was used.

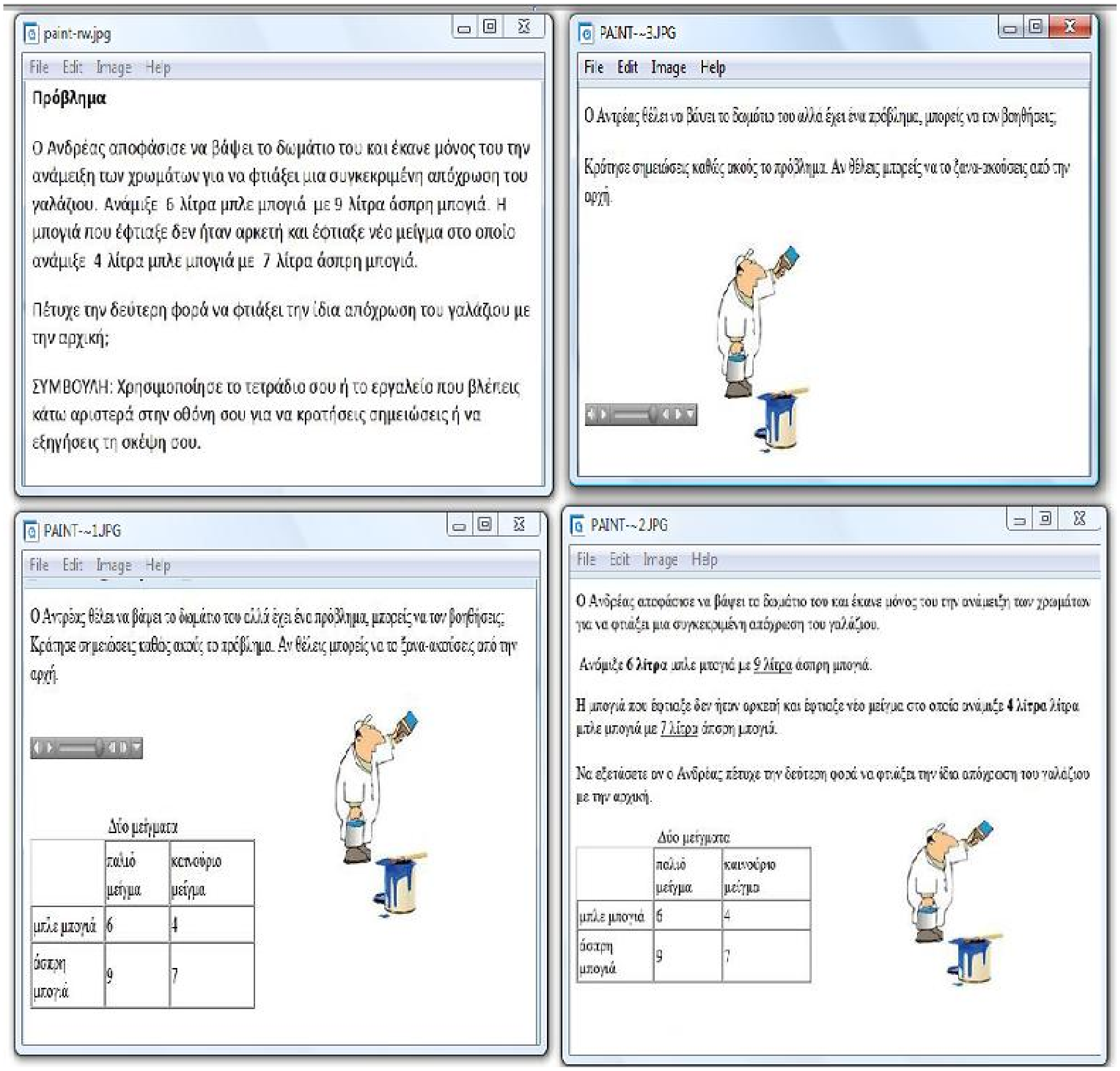



Figure 24 Media in accordance with the learning style

The figure above shows different versions of the same learning resource used to provide media in accordance to students' diagnosed learning styles using the VARK learning style model. This specific learning activity shown relates to the additive reasoning difficulty and it discusses a real life problem. Thus, the multimodal and the kinaesthetic version coincide and the figure illustrates four (instead of five) different versions of the learning resource.

Specifically, the adaptive e-courses fell into two categories, namely, (a) adaptive e-courses with one type of adaptation (e.g., non-linear learning flow), and (b) adaptive e-courses with two types of adaptation (e.g., non-linear learning flow and differentiated content adaptation).

In conjunction to the typologies of adaptive learning presented in Chapter 2, the e-courses have the following profile:

- provide adaptivity but not adaptability to the user, using a rule-based adaptation logic prescribed by the use of the IMS-Learning Design specification
- combine the macro-adaptive approach (adapting the content presentation to the students' learning styles) with the micro-adaptive approach (continuously adapting the allocation of resources to the student's errors and performance).

### 6.2.2 Student motivation measurements

The students completed a questionnaire by Berger and Karabenick (2011) on motivation in mathematics prior to the beginning of the interventions. Another version of the questionnaire, suitable for informatics, was developed in collaboration with one of the participating informatics teachers. Each of these two questionnaires was comprised of 11 multiple-choice questions that were evaluated using a 5-point Likert scale. The questions evaluated students' motivation in terms of (a) interest (i.e. enjoyment gained from the course), (b) utility (i.e.how useful the course is for the student's future), (c) attainment value (i.e importance of doing well on the course), and (d) cost (i.e. effort and lost opportunities). In total, 99 questionnaires were completed by the students, 71 by Informatics students and 28 by Mathematics students. Fifty-six students were included in the experimental group and 43 in the control group.

### 6.2.3 Course evaluation instrument

I designed the questionnaire and two participant teachers validated it, one of them teaches mathematics and the other one teaches informatics. Whenever time permitted it, the students answered the questionnaire anonymously, after the end of the intervention (N=62). It was inspired by Kirkpartick's (1976; 1994) four levels of evaluation of training effectiveness. The questionnaire was related to level 1, aiming at capturing students' satisfaction. During its design, Kirkpartick's (1996) implementation guidelines for measuring level 1 were taken into account. These are: a) determine what you want to find out, b) design a form that will quantify reactions,

c) encourage written comments and suggestions, d) attain an immediate response rate of a 100 percent and e) obtain honest reactions by making the sheet anonymous. It was comprised by four multiple choice (in a 5-point Likert scale) aiming to measure a) Q1: if students liked the course (1=not at all, …, 5=very much), b) Q2: if they would prefer this method (1= not at all, …., 5 = very much), c) Q3: the test items were relevant to the e- course (1= not at all,…, 5=very much), d) Q4: their perceived cognitive effort to learn with this method (1=large,…., 5 = small) and e) Q5: What they liked and what they didn't like about the course (open ended question, optional).

### 6.2.4 Procedures and data collection concerning the classroom interventions

A week before each intervention, all students completed the diagnostic learning style questionnaire in a printed format. I analysed the answers in order to diagnose the learning style of each student. With regards to the performance tests, the pre-test and the posttest were identical in each intervention. They contained problems and questions related to the inherent difficulties of the respective course topic. In the mathematics courses the students completed the tests in a printed format (using paper and pen) and they were mostly comprised by open-ended problems, whereas in the informatics course the students completed computerised tests with multiple choice questions. In the case of mathematics, the tests were graded by two participant mathematics teachers after being anonymised. In the case of informatics, the tests were automatically graded by the computer. Finally, before completing the pre-tests, the students completed the motivation questionnaire in a printed format.

The students were randomly assigned into experiment group and control group. The difference between the two groups in the gain scores was investigated. The gain scores were used for the assessment of students' performance improvement which can provide a vehicle for assessing the impact of the interventions (Dimitrov & Rumrill, 2003). The gain scores D were calculated using the formula $D = Y2 - Y1$, where Y1 = pretest scores and Y2 = posttest scores. They represent the independent variable in the independent samples t-test of the two groups.

## 6.3 Results

### 6.3.1 Participation in each intervention

Five teachers and 149 students from six different schools participated in the classroom interventions. Seventy of them were assigned to the control group and 79 to the experimental group. All participant teachers and students live in Cyprus. As shown in Table 11, the numbers of participant students involved in each intervention as well as their ages are varying.

**Table 11 Student participation in each intervention**

| Topic/ domain | Age of students involved | Number of students involved |
|---|---|---|
| Inequalities | 14 years old | 32 |
| Ratios and analogies | 12-13 years old | 28 |
| System of linear equations | 15 years old | 18 |
| WWW, internet and communication protocols | 14 years old | 51 |
| Main and auxiliary memory | 16 years old | 20 |

### 6.3.2 Student performance

The mean value of the gain scores (which indicates performance improvement) in the control group was equal to 1.737 (S.D. = 2.463), whereas in the focus group the mean value of the gain scores is 2.79 (S.D. = 2.814). Consequently, the mean difference in the performance improvement between the focus group and the control group is equal to 1.053 (out of 10 grades). The Mann-Whitney U test below indicates that this difference is significant. This is attributed to the fact that, in their majority, the students' grades before and after the interventions were relatively low: the mean performance in the pre-test was equal to 3.481 (out of 10) and in the post-test was equal to 5.766 (out of 10). This is justified by the nature of the pre-post tests: they did not have increasing difficulty level, but, instead, they were comprised by problems or questions related almost exclusively to the inherent difficulties or known misconceptions of the topic.

Two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of their values did not reveal them to be extreme and they were kept in the analysis. Gain scores were normally distributed for the focus group students but not for the control group students, as assessed by Shapiro-Wilk's test ($p < .05$). As already mentioned above, a Mann-Whitney U test was run to determine if there were differences in gain scores between control group students and focus group students. Distributions of the gain scores for control group students and focus group students were approximately similar, as assessed by visual inspection. Gain scores for focus group students (mean rank = 83.46) were statistically significantly higher than for control group students (mean rank = 65.45), $U = 3433.500$, $z = 2.552$, $p = .05$.

Gain scores and types of adaptation

The results below confirm the results reported by Tseng et al. (2008) who concluded that: a) a two-types adaptive learning environment is more helpful to students in enhancing learning efficiency compared to one-type adaptation and, b) the one-type adaptation is more efficient than the no-adaptation condition.

**Table 12Types of adaptation and student performance**

| Types of adaptation | N | Mean | Std. Deviation |
|---|---|---|---|
| None | 70 | 1.737 | 2.463 |
| One | 23 | 2.087 | 2.094 |
| Two | 56 | 3.079 | 3.030 |

### 6.3.3 Adaptive learning courses and students' motivation

I created the dichotomous variable "Motivation level" following the procedure shortly described below:

- Calculation of the mean value of the "motivation" variable (N=99), which was equal to 3.36
- Recode the values of the "motivation" variable (input variable) into the values of the "motivation level" variable (output variable). Those values of the input variable that were less than 3.36 were categorized as "low" in the output variable, whereas values of the input variable equal or greater than 3.36 were categorized as "high" in the output variable.

Gain scores were normally distributed for both low- and high-motivated students, as assessed by Shapiro-Wilk's test ($p > .05$). Also, there were no outliers in the data, as assessed by inspection of a boxplot and there was homogeneity of variances for engagement scores for males and females, as assessed by Levene's test for equality of variances ($p = .949$). Consequently, an independent samples t-test was run to determine if there were differences in gain score between lowly-motivated and highly motivated students. The result indicated no statistically significant difference, $t(54) = -.109$, $p = .914$.

### 6.3.4 Adaptive learning courses and students' prior knowledge

The values of the pretest scores of the respective (input) variable were coded into three categories in the output variable "Prior Knowledge", as follows:

- students with pretest scores within the range (0, first quartile of the input variable) were coded as "0" in the output variable; they represent students with low prior knowledge with regards to the topic at stake since their scores are included in the lower 25% of the scores measured in ascending order
- students with pretest scores within the interquartile range were coded as "1"; they represent students with moderate prior knowledge with regards to the topic at stake since their scores are included between the 25% and the 75% of the scores measured in ascending order

- students with pretest scores within the range (third quartile of the input variable, 10) were coded as “2”; they represent students with high prior knowledge with regards to the topic at stake since their scores are included in the higher 25% of the scores measures in ascending order.

The distribution of the students that undertook the adaptive learning courses with regards to the prior knowledge levels, as these are defined above, is depicted in the table below.

**Table 13 Student prior knowledge and gains (adaptive e-learning)**

| | N | Mean | Std. Dev. | Std. Error | 95% Confidence Interval for Mean | | Min. | Max. |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| 0(low) | 20 | 4.160 | 2.5159 | .5626 | 2.983 | 5.337 | .0 | 8.7 |
| 1(moderate) | 42 | 3.153 | 2.6471 | .4085 | 2.328 | 3.978 | -2.0 | 8.0 |
| 2(high) | 17 | .281 | 1.9327 | .4688 | -.713 | 1.274 | -2.7 | 4.0 |
| Total | 79 | 2.790 | 2.8136 | .3166 | 2.160 | 3.420 | -2.7 | 8.7 |

An one-way ANOVA was conducted to determine if the Gain Scores were different for groups with different prior knowledge (as determined by the pretest scores). Participants were classified into three groups: low (n = 20), moderate (n = 42) and high levels of prior knowledge (n = 17). There were no outliers, as assessed by boxplots. Data was normally distributed for each group, as assessed by Shapiro-Wilk test ($p > .05$); and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances ($p = .377$). Data is presented as mean ± standard deviation. Gain score was statistically significantly different between different prior knowledge groups, $F(2,76) = 12.208$, $p < .0005$, $\omega 2 = 0.22$.Gain score decreased from low (4.1 ± 2.5), to moderate (3.2 ± 2.6) to high (.281 ± 1.93) prior knowledge groups, in that order. Tukey post-hoc analysis revealed that the decrease from moderate to high (2.87, 95% CI, $p = .000$) was statistically significant, as well as the decrease from low to high (3.88, 95% CI, $p = .000$).

### 6.3.5 Adaptive learning courses and students’ age/grade

There were no outliers in the data, as assessed by inspection of a boxplot. Gain scores were normally distributed between the age levels, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of variances, as assessed by Levene's Test of Homogeneity of Variance (p = .092). There were no statistically significant differences in Gains Scores between the different age groups, F(4,74) = 1.482, p = .216.

### 6.3.6 Adaptive learning courses and learning styles

As seen from the boxplot below, there were two outliers, but they were not extreme.

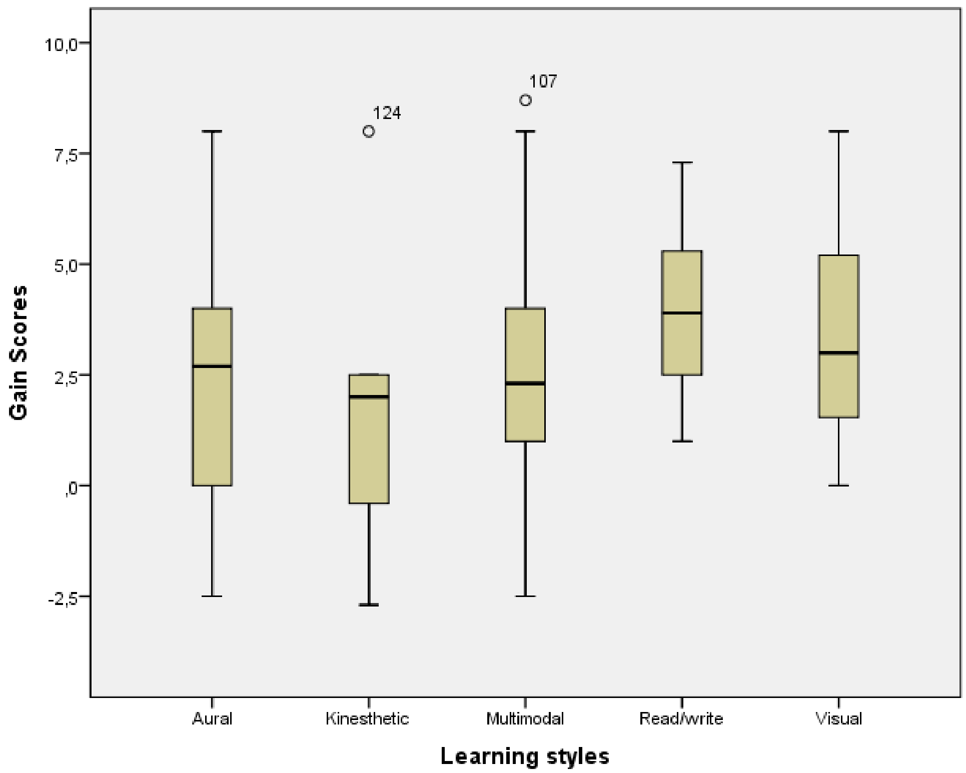



Figure 25 Boxplot of Gain scores across learning styles

The majority of the focus group students were multimodal type of learners (n=46 students or 58,2 %), followed by aural types (n=18 students or 22,8%). The remaining students can be equally divided in visual, read/write and kinesthetic types of learners (each group is comprised by 6 students which corresponds to the 6,3% of the focus group sample). Since the numbers of the students included in the latter groups (e.g. visual, read/write, kinesthetic) are small (a rule of thumb is at least seven students per group), no reliable inferential analysis would be possible. This information is illustrated in Table 14.

As shown in Table 15, the mean gain score for the Aural types is equal to 2,782 (st. dev= 3,17), for the kinesthetic type is equal to 1,88 (st. dev. = 4,00), for the multimodal type is equal to 2,678 (st. dev. = 2,60), for the read/write type is equal to 4 (st. dev. = 2,44) and for the visual type is equal to 3,548 (st. dev. = 3,14). Since the frequencies of the kinesthetic, the read/write and the visual type are low these numbers are only indicative about the relative difference in the gain scores between the five types of learners.

**Table 14 (Relative) frequencies of Gain scores**

| | Learning styles | Frequency | Relative frequency |
|---|---|---|---|
| Gain Scores | Aural | 18 | 22,8% |
| | Kinesthetic | 5 | 6,3% |
| | Multimodal | 46 | 58,2% |
| | Read/Write | 5 | 6,3% |
| | Visual | 5 | 6,3% |

**Table 15 Basic descriptive measures of gain scores across learning styles**

| | Learning Styles | | Statistic | Std. Error |
|---|---|---|---|---|
| Gain Scores | Aural | Mean | 2,782 | ,7465 |
| | | Std. Dev. | 3,1670 | |
| | Kinesthetic | Mean | 1,880 | 1,7892 |
| | | Std. Dev. | 4,0009 | |
| | Multimodal | Mean | 2,678 | ,3837 |

| | | | |
|---|---|---|---|
| | Std. Dev. | 2,6021 | |
| Read/Write | Mean | 4,000 | 1,0918 |
| | Std. Dev. | 2,4413 | |
| Visual | Mean | 3,548 | 1,4049 |
| | Std. Dev. | 3,1415 | |

**Alternative route for an integrated statistical analysis using ANCOVA**

In order to to determine whether there are any statistically significant differences between the adjusted population means of independent groups, an ANCOVA (Analysis of Covariance) test could be exploited, in which

- the independent variable is the groups of students (group 1: no adaptation, group 2: one adaptation method, group 3: two adaptation methods),
- the covariate variables are students' age and pre-test grades and
- the dependent variable is the post-test grades.

It is assumed that the covariate, pre-test score, is linearly related to the dependent variable, post-test score, for all groups of the independent variable, adaptation group. But, as shown in the scatterplot below, the assumption of linearity is violated.

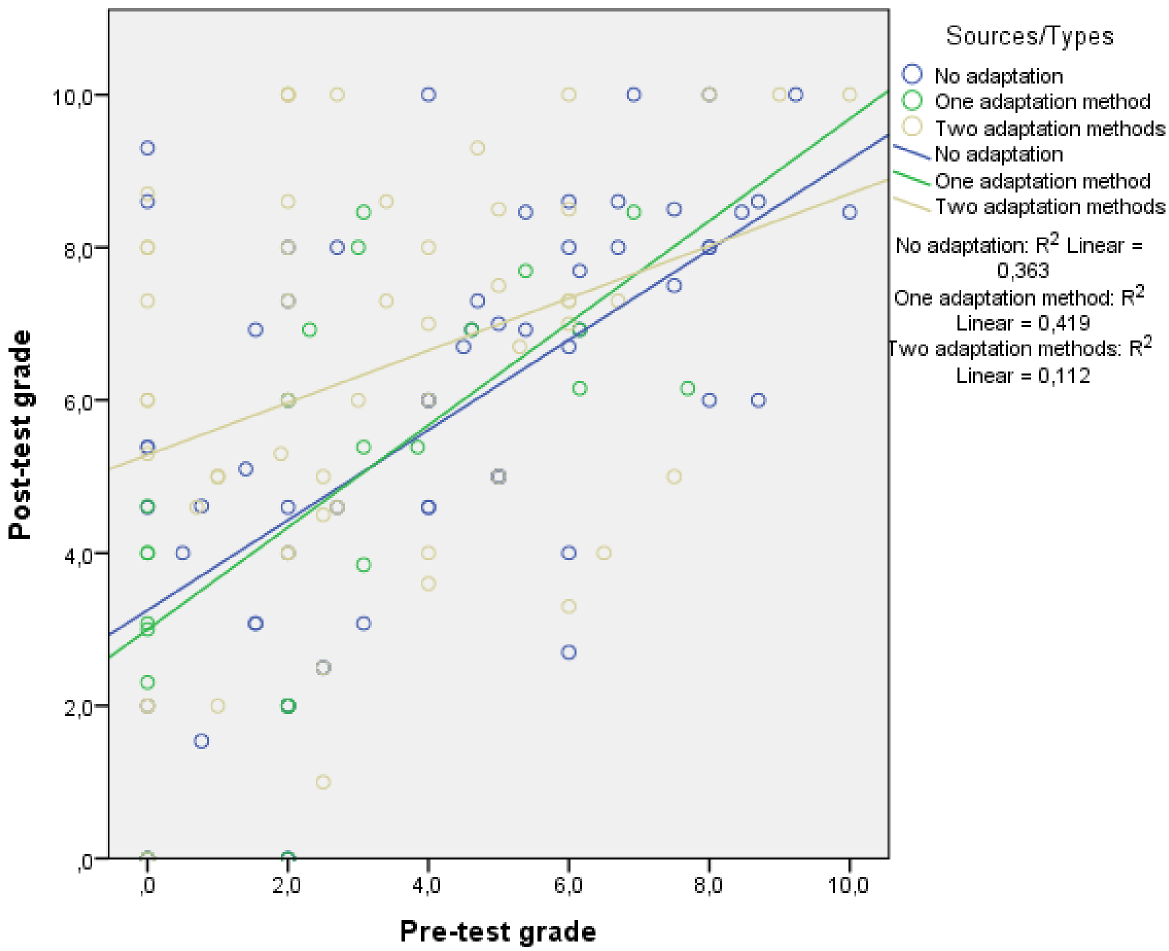



**Figure 26 ANCOVA –Scatterplot (pre-test grade, post-test grade)**

Thus, in order to run a valid ANCOVA statistical test, to coax the data to have a linear relationship by transforming the covariate, pre-test score. Yet, the transformation of the covariate did not eliminate the problem. Consequenlty, the results below are valid to the extent in which the ANCOVA method is robust against the violation of linearity.

**Table 16 ANCOVA- Tests of Between-Subject Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 392,995[a] | 11 | 35,727 | 7,266 | ,000 |
| Intercept | 3,302 | 1 | 3,302 | ,672 | ,414 |
| Adaptation * pretest | 23,660 | 2 | 11,830 | 2,406 | ,094 |
| Adaptation * Age | 17,993 | 2 | 8,997 | 1,830 | ,164 |
| Adaptation * Learning Style | 24,677 | 2 | 12,338 | 2,509 | ,085 |
| Adaptation | 6,397 | 2 | 3,198 | ,650 | ,523 |
| pretest | 151,200 | 1 | 151,200 | 30,752 | ,000 |
| Age | ,078 | 1 | ,078 | ,016 | ,900 |
| Learning Style | ,484 | 1 | ,484 | ,098 | ,754 |
| Error | 673,591 | 137 | 4,917 | | |
| Total | 6037,629 | 149 | | | |
| Corrected Total | 1066,586 | 148 | | | |

Notes: a. R Squared = ,368 (Adjusted R Squared = ,318)

There was homogeneity of regression slopes as the interaction terms (pre-test grade, learning style and age) were not statistically significant, F(2,137) = 2.509, p = .085 (for Learning style) F(2,137) = 1.830, p =.164 (for students' age) and F(2,137) =2.406, p = .094 (for pre-test grades). Also, standardized residuals for the interventions and for the overall model were normally distributed, as assessed by Shapiro-Wilk's test (p > .05).

**Table 17 ANCOVA- Tests of Normality for the standardized residuals**

| Sources/Types | | Kolmogorov-Smirnov[a] Statistic | df | Sig. | Shapiro-Wilk Statistic | df | Sig. |
|---|---|---|---|---|---|---|---|
| Standardized Residual for posttest | No adaptation | ,077 | 70 | ,200* | ,985 | 70 | ,554 |
| | One adaptation method | ,130 | 23 | ,200* | ,972 | 23 | ,743 |
| | Two adaptation methods | ,074 | 56 | ,200* | ,972 | 56 | ,228 |

Notes: *. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

**Table 18 ANCOVA- Tests of Normality for the overall model**

| | Kolmogorov-Smirnov[a] Statistic | df | Sig. | Shapiro-Wilk Statistic | df | Sig. |
|---|---|---|---|---|---|---|
| Standardized Residual for posttest | ,060 | 149 | ,200* | ,988 | 149 | ,223 |

Notes: *. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

There was homoscedasticity and homogeneity of variances, as assessed by visual inspection of a scatterplot and Levene's test of homogeneity of variance (p = .581), respectively.

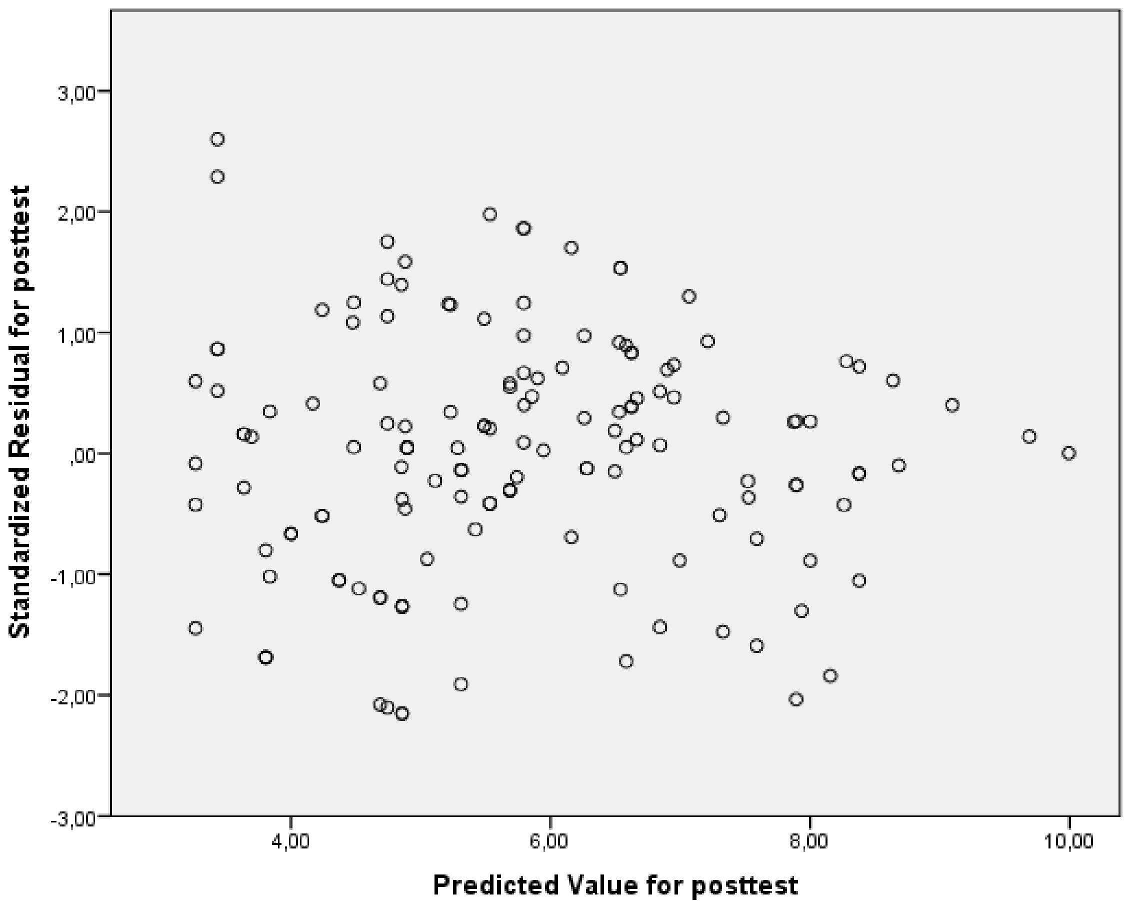



**Figure 27 ANCOVA – scatterplot (predicted value, satnadardized residual)**

**Table 19 ANCOVA - Levene's Test of Equality of Error Variances**

| F | df1 | df2 | Sig. |
|---|---|---|---|
| ,545 | 2 | 146 | ,581 |

Notes: Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + pretest + Age + Learning Style + Adaptation

Also, there were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations.

**Table 20 ANCOVA- Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 325,362[a] | 5 | 65,072 | 12,554 | ,000 | ,305 |
| Intercept | ,569 | 1 | ,569 | ,110 | ,741 | ,001 |
| pretest | 267,826 | 1 | 267,826 | 51,670 | ,000 | ,265 |
| Age | 20,179 | 1 | 20,179 | 3,893 | ,050 | ,027 |
| Learning Style | ,709 | 1 | ,709 | ,137 | ,712 | ,001 |
| Adaptation | 49,569 | 2 | 24,784 | 4,781 | ,010 | ,063 |
| Error | 741,224 | 143 | 5,183 | | | |
| Total | 6037,629 | 149 | | | | |
| Corrected Total | 1066,586 | 148 | | | | |

Notes: a. R Squared = ,305 (Adjusted R Squared = ,281)

After adjustment for students' age, learning style and pre-test grades, there was a statistically significant difference in post-test grades between the interventions, $F(2,143) = 4.781$ $p < .05$, partial $\eta 2 = .063$.

**Table 21 ANCOVA – estimates**

| Sources/Types | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| No adaptation | 5,381[a] | ,277 | 4,834 | 5,928 |
| One adaptation method | 5,128[a] | ,479 | 4,181 | 6,075 |
| Two adaptation methods | 6,536[a] | ,311 | 5,921 | 7,151 |

Notes; a. Covariates appearing in the model are evaluated at the following values: Pre-test grade = 3,481, Age = 14,11, Learning Style = 4,13.

Post hoc analysis (pairwise comparisons) was performed with a Bonferroni adjustment. Post-test grades were statistically significantly lower in the control trial vs the two adaptation methods intervention ($p < .05$) and in the one adaptation method intervention Vs two adaptation methods intervention ($p < .05$).

**Table 22 ANCOVA - Pairwise comparisons**

| (I) Sources/Types | | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| No adaptation | One adaptation method | ,253 | ,554 | 1,000 | -1,090 | 1,595 |
| | Two adaptation methods | -1,155* | ,423 | ,022 | -2,181 | -,129 |
| One adaptation method | No adaptation | -,253 | ,554 | 1,000 | -1,595 | 1,090 |
| | Two adaptation methods | -1,408* | ,573 | ,046 | -2,797 | -,019 |
| Two adaptation methods | No adaptation | 1,155* | ,423 | ,022 | ,129 | 2,181 |
| | One adaptation method | 1,408* | ,573 | ,046 | ,019 | 2,797 |

Notes: Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

b. Adjustment for multiple comparisons: Bonferroni.

### 6.3.7 Adaptive learning courses evaluation by the students

Concerning the validity of the questionnaire, the scale had a high level of internal consistency, as determined by a Cronbach's alpha of 0.811. The table below shows the mean, the median and standard deviation for each item ( "Q1" to "Q4"). These descriptive statistics come from the manner in which the variables were coded.

**Table 23 Courses evaluation by the students**

| | Q1 (like) | | | | | | Q2 (prefer) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | | Focus | | | Control | | | Focus | | |
| | Mean | Median | Std.D | Mean | Median | Std.D | Mean | Median | Std.D | Mean | Median | Std.D |
| Statistics | 3.37 | 3.00 | 1.217 | 3.31 | 3.00 | 1.061 | 3.37 | 3.00 | 1.273 | 3.38 | 3.50 | 1.314 |
| Std. Error | .222 | | | .188 | | | .232 | | | .232 | | |

| | Q3 (relevance) | | | | | | Q4 (perceived effort) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | | Focus | | | Control | | | Focus | | |
| | Mean | Median | Std.D | Mean | Median | Std.D | Mean | Median | Std.D | Mean | Median | Std.D |
| Statistics | 3.83 | 4.00 | 1.020 | 4.00 | 4.00 | 1.107 | 3.13 | 3.00 | 1.074 | 3.25 | 3.00 | 1.164 |
| Std. Error | .186 | | | .196 | | | .196 | | | .206 | | |

The following inter-item correlation matrix indicates that all the items correlate positively[30] with each other. The consequence of a low or negative inter-item correlation, even with just one item, is a reduction in the value of the reliability coefficient.

**Table 24 Inter-Item Correlation Matrix**

| | Q1(like) | Q2(prefer) | Q3(relevance) | Q4 (effort) |
|---|---|---|---|---|
| Q1 (like) | 1.000 | .782 | .666 | .429 |
| Q2 (prefer) | .782 | 1.000 | .444 | .373 |
| Q3(relevance) | .666 | .444 | 1.000 | .416 |
| Q4 (effort) | .429 | .373 | .416 | 1.000 |

### 6.3.8 Discussion with teachers

The teachers that participated in the design were also present during the interventions in their respective classes. Three of them discussed with me after the end of the intervention. In triangulating the results of the respective e-courses with the opinions of the teachers, two conclusions may be drawn:

- teachers said that they believe that the adaptive learning method might have been more helpful for the mediocre students, in terms of performance in the course. This can only be confirmed if we consider the performance in the pre-test as the sole indicator of their performance.

- teachers said that they believe that both the adaptive and the non-adaptive course attracted the interest of the students. Judging from the results of the course evaluations by the students, while it is evident that both groups (focus group and control group) graded the courses similarly, the evaluation scores range between 3 and 3,5 (out of five) indicating a discrepancy.

### 6.3.9 Validity

**Internal Validity**

As already discussed in Chapter 3, some of the most well-known threats to internal validity are (Bergh et al. 2004; Brewer, 2000; Cook & Campbell, 1979): Self-selection effects, Experimental mortality, History, Maturation effects, Regression toward the mean effects, Testing and Instrumentation.

From the above threats, regression towards the mean effects and testing are those that could be considered as probable to this study. Concerning the former: students were randomly assigned with regards to their pre-test scores to the intervention conditions (adaptive versus non-adaptive learning mode). Thus, regression toward the mean effects can be considered as not highly probable. With regards to the later, it constitutes a threat to the one group design, not a threat to the two group design, since both groups are exposed to the pre-test and consequently, the difference between groups is not due to testing.

**External Validity**

External validity can be divided into population validity and ecological validity (see Chapter 3). With regards to the population validity, confidence that the research sample shared similar characteristics to the population provide the diversity concerning: the age of students (12-16 years old), the subjects they studied (5 different topics), the respective domains of study (Mathematics and Informatics) and their gender (54% females, 46% males).

With regards to the ecological validity, both Mathematics and Informatics are included in the STEM domain. The fact that topics and domains outside STEM were not included in the research constitutes an ecological validity limitation. Finally, as this is always the case in research where people and their behavior play the first role, it might suffer from the Hawthorne effect (Jones, 1992).

On the one hand, design research aims for ecological validity, in that, the description of the results should provide a basis for adaptation to other situations(Gravemeijer & Cobb, 2006) and an empirically grounded theory of how the intervention works facilitates this requisite (ibid). But the fact the research described in this chapter was constrained to a single geographic area (two towns of a small European country) constitutes a threat to the ecological validity of the research.

**Validity of the VARK diagnostic questionnaire**

An inspection of the related literature conducted didn't identify a study in which the validity of the VARK questionnaire is criticized or questioned. On the contrary, a study conducted by Leite et al. (2010) supports the use of the VARK as a low-stakes diagnostic tool by students and teachers and encourages its use as a way of helping students identify their preferences. Finally, the author of this thesis confirms that "large amount of material provided on the VARK Web site to help learners adapt their learning strategies to materials representing different modes of presentation are definitely useful" (Leite et al, 2010, p. 336).

## 6.4 Discussion

Five adaptive e-courses were tested in real classroom settings. Out of the five e-courses, the one about analogies and ratios was the pilot course which was formed concurrently with the formation of the adaptive eLearning strategy (see previous chapter). This adaptive eLearning strategy was incorporated in all five e-courses. The students that followed the adaptive e-courses performed significantly better compared to those students that followed non-adaptive e-courses. Regarding the association of the students profile with their gain scores: in the question "Were the adaptive learning e-courses more beneficial for low-motivated learners?", the answer is negative. No significant difference was indicated by the Mann Whitney U test. In addition, no significant differences on the gain scores between the different student age groups were recorded, which provides a negative answer to the question "Were the adaptive learning e-courses more beneficial for specific age groups?". On the contrary, in the question "were the adaptive learning interventions more beneficial for students with low pretests scores?", the answer is positive. It should be noted though that the purpose of these questions is to shed light on the profile of the students that were most benefited by the specific adaptive learning interventions. The statistical associations do not necessarily imply causal relationships.

In this research the unit of analysis is not the concept per se, but the inherent difficulties that are revolved around it. As seen, one concept may be related to more than one difficulties. Thus, my approach is distinctively different from the approaches 1 to 3 mentioned in section 6.2.2. As already mentioned by the authors of the first paper in the literature review section, the degree of understanding of a concept in a test is not easy to measure. On the contrary, in Goguadze et al. (2011) the unit of task analysis is not the concept but the misconceptions of a given problem. They follow a non-deterministic approach which yields to a more sophisticated model compared to mine, in which the problem was connected only to one misconception. Practically this means more effort on behalf of the learning designer to identify problems that are connected only to one misconception. The deterministic approach I followed can be attributed to the use of deterministic Finite State Machines behind of the adaptation logic of any IMS-LD compliant Unit of Learning. Indeed, in order to create the adaptive e-learning courses I had to design the respective FSMs and moreover to implement a large number of production rules, which was a complex process. This has two implications:

a) a design requirement, which was mirrored in the environment discussed in the next chapter: a user-friendly and IMS-LD compliant tool for the authoring of adaptive e-Learning components has to hide from the designer this complexity

b) there is a need to rethink the IMS-Learning Design specification per se (IMS GLC, 2003) so that it can support effectively non-deterministic models.

Another point of differentiation with these approaches is that they do not clearly mention the role of the teacher in relation to the identification of misconceptions, whether it was the teacher or an expert who opinionated about the issue and whether their opinion was the sole source of information about the issue. On the contrary, in the case of Goguadze et al. (2011) the identification of misconceptions and frequent errors is based on the results of a literature review conducted by the authors. In the approach of Chen (2014), the role of the experts in providing scaffolds is crucial. It is not clearly mentioned whether the experts are also tutors though and this is important information since the body of knowledge between these two roles is different (e.g the difference between content knowledge and pedagogical content knowledge). On the other hand, in the research effort described in this chapter students with lower levels of prior knowledge demonstrated greater levels of improvement in their learning outcome than those with medium to high levels of prior knowledge, which was also the case in Chen (2014).

Future plans involve further experimentation with a variety of different topics and domains while keeping the same rationale (overcoming the inherent difficulties of the subject matter), methodology and the same adaptive eLearning strategy for the design and the development of the e-courses. Since the inherent difficulties of a learning topic apply universally, the affordances of adaptive e-learning may serve as a starting point for creating (online) communities of interest worldwide that use it for the purpose of overcoming those difficulties. This is important also due to the fact that alignment across national curricula in Europe and worldwide is incomplete and these inherent difficulties may serve as reference points ("anchors") for the creation of such communities of interest, in which the concept of "teachers as designers" could be further extended in the domain of adaptive e-learning.

# Chapter 7A framework for the design of a user-friendly & all-encompassing adaptive eLearning environment

When designing educational technology environments or activities, ideally the design should embrace opportunities for:

- promoting a culture of participatory educational design
- discussing education and the role of technology at a design level in order to describe challenging situations and identify possible solutions
- a common language for collaboration and co-ordination at the design level (Mor et al, 2014).

This chapter seeks to address the first two points, while capturing and communicating design knowledge in the adaptive elearning field. More specifically, this knowledge relates to the design of a tool that facilitates adaptive e-learning and Learning Design. With respect to Learning Design (LD), Katsamani & Retalis (2013) claim that there is no ideal visual LD language or tool that can fully meet the diverse teachers' needs and that the design of such a tool still remains an open research issue.

The active involvement of the teachers in the process of authoring scenarios and courses for adaptive e-learning requires proper and user-friendly tools. To this end, this chapter proposes a solution by presenting a) design requirements that they can serve as a guiding framework to adaptive e-Learning system developers and b) the ensuing User Interface mockups. The results of this chapter respond to the questions: a) how can we design a learning environment for adaptive learning in a user-centered way?, and, b) how can we prioritise the design requirements of a digital environment in a user-centered way?

## 7.1 Requirements engineering

For the scope of this chapter, requirements are understood to be statements about situations which describe "needs and opportunities for new tool support, as well as envisioned situations, enhanced, and perhaps otherwise transformed, by a design intervention" (Carroll et al, 1998, p. 1156). Scenarios, as well as use cases, have proved useful in eliciting requirements in envisioned situations (Rolland et al, 1999; Potts, 1994; Carroll, 1995; Carroll, 2000). In the context of this chapter a use case is defined as "a concrete description of activity that the user engages in when performing a specific task, description sufficiently detailed so that design implications can be inferred and reasoned about”(Carroll, 1995).

Requirements elicitation is defined here as "the process of identifying needs and bridging the disparities among the involved communities for the purpose of defining and distilling requirements to meet the constraints of these communities" (Christel & Kang, 1992, p.3). Moreover, requirements specification can be conceived as a contract between stakeholders that defines the desired functional behaviour of the software, as well as other non-functional properties (such as performance, reliability etc.) without justifying how such functionality will be achieved (Loucopoulos & Karakostas, 1995). The process of specification requires input knowledge about the problem domain which is supplied by the elicitation process. The output is the requirements specification model, which serves as a means of specifying what constitutes the problem that must be solved by the software system, as well as, a blueprint for its development (ibid). Lastly, requirements validation certifies that “requirements are an acceptable description of the system to be implemented” (Paetsch, Eberlein & Maurer, 2003).

## 7.2 Approach

In the real world, design practice usually involves a small-group of stakeholders working together over an extended period of time, with a variety of design tasks (Turner & Cross,  2000), which is the case described in this chapter. The first step of my methodology is the scenario-based requirements elicitation process of the envisioned system. Participants were asked to envision and describe a scenario of use concerning an adaptive learning system of ideal for them characteristics and functionality. The scenario-based approach was the basis for truly co-operative design in which end-users were not only part in requirements validation but active participants in the whole design process.

Except for the scenarios of the envisioned environment authored by the participants, the following constituted sources of knowledge for me in the requirements analysis process (Loucopoulos & Karakostas, 1995):

a) literature about the domain; in the domain of adaptive learning systems design accumulated knowledge exists in the recent bibliography (challenges, opportunities, previous experience, future directions etc) that need to be taken into account

b) previous experience in similar design domains; the question of how we could apply to LD insights derived from the discourse with other design disciplines is an interesting aspect that has begun to flourish and to attract the attention of the stakeholders (Mor & Craft, 2012; Mor et al., 2013; Mavroudi & Hadzilacos, 2013). An example is the practice of computer supported collaborative design.

c) the existing software systems in the domain; in addition to the systems mentioned in the previous section, the LAMS (Learning Activity Management System) which is a system close to the Learning Design philosophy that has gained the acceptance of the educational community was also studied.

d) common sense on behalf of the requirements analyst .

In addition to these knowledge sources, as it has been mentioned in Chapter 1, another knowledge source was the conjectures i.e. implications on the design derived from the work discussed in chapters four and six. These are the following: a) use the VARK model as the basis of adaptation pertaining to learning styles (Chapter 4), b) provide the means to implement a complex adaptive eLearning strategy in which more than one adaptation method is enacted upon more than one adaptation parameters (Chapter 6), c) provide a visual graphical user interface in order to hide that complexity (Chapter 6), d) provide CSCD options (Chapter 4). Also, the interaction between the teacher and the sub-system of the digital environment who is responsible for the creation/authoring of the adaptive e-courses is based on the collaboration protocol mentioned in Chapter 5. That is, the "dialogue" between the teacher, as the end user, and the sub-system tries to mimic the "dialogue" between me and the teachers in the process of creating the course diagram of the adaptive e-course. In turn, as already discussed, the discussion protocol is based on the two theoretical frameworks mentioned in Chapter 5.

The next step at the requirements engineering process involved the requirements specification. In this phase, the Grounded Theory (see Chapter 3) was used as a method of extracting the requirements from the scenarios of the envisioned system authored in the previous step. The codes, concepts and categories emerged from the written scenarios using the Grounded Theory and, following, they were incorporated in an informal graphical model. The purpose of this model was to communicate the needs and wants with regards to the envisioned system (Halaweh, 2011;

Halaweh et al., 2011). In addition, I created a set of use cases that described functional and non-functional requirements in a more formal and elaborative way. Requirements validation was not considered as a separate activity, but part of requirements specification aiming to examine the relevance, consistency etc of the requirements assimilated. Next, I and the authors of the scenarios participated in a Preliminary Design Review (PDR) meeting (Rosenberg, & Stephens, 2007) in order to discuss and evaluated the informal model and the use cases. (The agenda of the PDR meeting is described in the Annex 1.) The meeting was organized by me and its purpose was to reconvene if more research was necessary to finalize the design approach in order to follow up on assigned action items or not. The conclusions of this meeting helped me in making refinements in the informal model, in the description of use cases and in the use cases diagrams. Following, I designed User Interface (UI) mockups using a dedicated software tool[31]. Once created, they were disseminated again along with explanatory texts to the small group of authors that had also participated in the PDR meeting. They were further criticized by the participants and again, I made refinements.

As already mentioned, the proposed environment is comprised of two main sub-systems:

- an editor, responsible for the creation/authoring of adaptive Units of Learning
- a player, responsible for the implementation of adaptive Units of Learning

The intended use of the latter involves the enactment of the ensuing Units of Learning in various settings, including virtual or real classroom settings. Consequently, in the requirements validation process concerning this specific sub-system, participatory design with children (Muller et al, 1994; Druin, 1999) took place, in which children worked with the researcher to collaboratively refine or change the design of the UI mockups. Using a brainstorming technique and considering "children as technology design partners" (Druin, 1999; Guha, 2005), the researcher identified new technology possibilities and features of the player sub-system that might not have been considered otherwise.

In the closing step of the Requirements Engineering, the final version of the UI mockups and accompanying explanatory texts were once again disseminated to all scenarios authors along with

[31] http://creately.com/

an evaluation questionnaire. The purpose of the questionnaire was to gauge the extent in which the proposed design solution a) could actually solve the problems that were originally identified and b) met the participants' expectations.

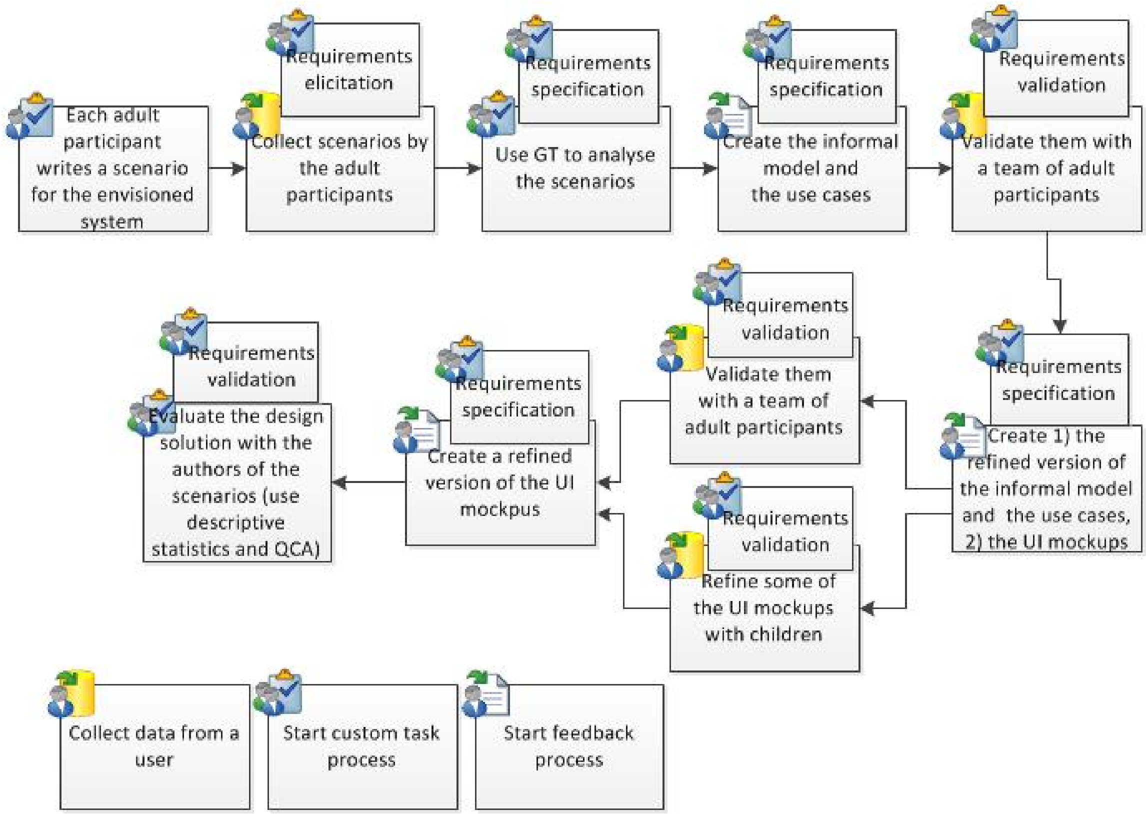



Figure 28 The diagram of the approach

In the figure above, the diagram of the approach is depicted, along with mappings between the steps of the approach with the general RE methodology.

## 7.3 Method & participants

With regards to the adults participants' profile, they were aged between 28-45 years old, the majority of them (thirteen participants) living in Greece and the rest of them (seven participants) in Cyprus. Eight of them were females and twelve of them males. Fourteen of them were educators mostly teaching courses within the STEM (Science, Technology, Engineering, Mathematics) domain and the rest were professionals in ICT-related topics. All of them were familiar with Learning Design and specifically with the design of adaptive e-courses, as a part of postgraduate formal course in educational technology which they had completed in the context of open and distance tertiary education. In addition, eight children (five boys and three girls) participated in the requirements engineering endeavor (aged 12-13 years old), all of them living in Nicosia, Cyprus. They were familiar with the use of ICT in their respective classrooms.

Initially, a scenario of an envisioned system was administered to the adult participants in a written form in order to fully grasp the idea of what such a scenario of an envisioned system actually is. Then, they wrote their own scenario of an ideal adaptive learning environment. The document that was administered to the participants is available in Annex 6. Consequently, I were gathered and coded twenty scenarios using the GT methodology. (The concepts and the codes emerged are mentioned in Annex 2.) Following, I created the informal model whose final version is depicted in the figure below. The codes emerged are depicted with rectangular shapes in the model and the concepts are depicted with elliptical shapes. Some concepts were further grouped conceptually into categories. They are denoted in the model with elliptical shapes which have double lines around them: collaboration, user-friendliness and scenario handling. The core category (see step 3 of the GT methodology) is labeled as "teacher's needs".

Next, the creation of the use cases, the use cases diagrams and the UI mockups along with accompanying descriptive texts followed, as described in the previous section. The design of UI mockups was influenced by the end users perceptions (adults and children) as well as by my knowledge about the challenges that the design needed to address. The three iterative cycles of requirements specification and validation that took place, lasted almost one month. The latest version of the UI mockups along with the accompanying texts is available in English (the original text was in Greek) in Annex 5.

The questions upon which the final designs were evaluated against deal with crucial problems mentioned in the literature impregnated with the end users' needs. For example, participants were asked whether: the proposed design alleviates the problem of visualisation of LD events, the organisation hides the sequence of LD events, the envisioned environment might be suitable for an educator with average technical knowledge etc. (The complete set questions which comprise the final evaluation survey is available in Annex 3.) Literally, the evaluation questionnaire that I administered to the adult participants at the end of the process was comprised by 12 closed, mandatory statements (using in a five point Likert scale, where "1" indicated complete disagreement with the respective statement and "5" indicated complete agreement with the respective statement) and one open-ended, optional question, asking for the participants' comments.

Fifteen respondents successfully completed the questionnaire. Seven of them are living in Greece and eight of them in Cyprus; eight of them are males and seven of them are females. All of them are amongst the twenty authors of the scenarios concerning the envisioned system.

In the next section the analysis of the questionnaire results involves statistical analysis (basic descriptive and correlational statistics) along with the data analytic strategy used here, which is known as use of Qualitative Comparative Analysis (QCA).

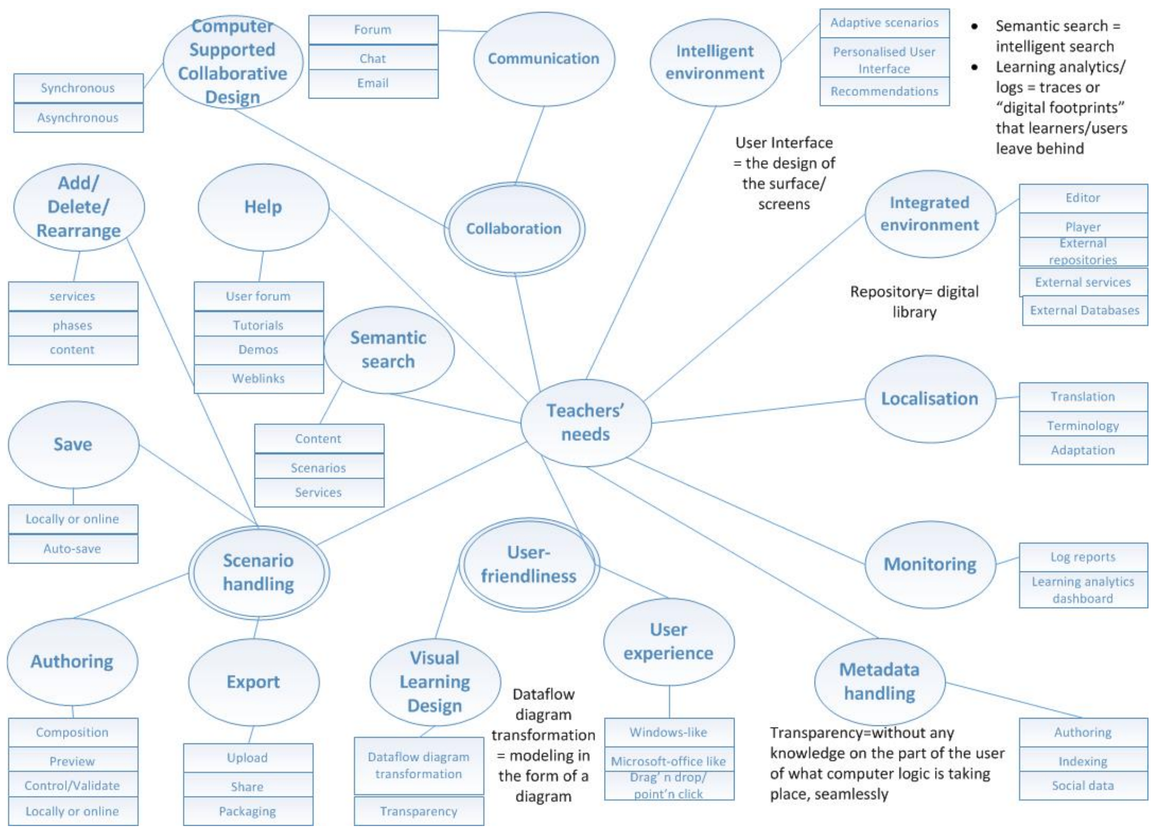



Figure 29 The final version of the informal model

## 7.4 Results

### 7.4.1 Descriptive statistics

The results of the evaluation questionnaire are shown in the table below:

**Table 25 Results of the evaluation questionnaire**

| Question: “Does the proposed environment provide solutions/cater for…” | Mean (M) and Standard Deviation (S.D.) of the responses |
|---|---|
| User help | M = 4.3, S.D. = 0.8 |
| Visualised Learning Design | M = 4.2, S.D. = 0.5 |
| Reduced complexity in the authoring process | M = 4.2, S.D. = 0.7 |
| “Rich” adaptive learning designs | M = 4.2, S.D. = 0.7 |
| Adaptation (i.e. the system adapts itself) to the user needs | M = 4.1, S.D. = 0.5 |
| Changes in an existing Unit of Learning | M = 4.0, S.D = 0.5 |
| Windows-like or/and Microsoft-like environment | M = 3.9, S.D. = 0.8 |
| Collaboration (between designers) | M= 3.9, S.D. = 0.6 |
| The average user does not have technical knowledge | M = 3.9, S.D. = 0.8 |
| Learners’ activity tracking | M = 3.6, S.D. = 1.0 |
| Debugging functionalities | M = 3.1, S.D. = 1.1 |

Finally, in the question “To what extent does the proposed environment meet your expectations?”, the mean average of the answers was equal to M= 4.0 (S.D. = 0.6).

In addition, for each of the aspects already mentioned, the participants had to declare whether the proposed environment provides better solution or caters better compared to the other IMS-LD tools they have worked with[32].

**Table 26 Results of the evaluation questionnaire – comparison with other LD systems**

| Question: "In comparison to the tools that you have worked with, does the proposed environment provide better or worse solutions for…" | Responses | |
|---|---|---|
| | Better (%) | Worse (%) |
| User help | 100 | 0 |
| Visualised Learning Design | 100 | 0 |
| Reduced complexity in the authoring process | 100 | 0 |
| "Rich" adaptive learning designs | 93.3 | 7.7 |
| Adaptation (i.e. the system adapts itself) to the user needs | 100 | 0 |
| Changes in an existing Unit of Learning | 100 | 0 |
| Windows-like or/and Microsoft-like environment | 100 | 0 |
| Collaboration (between designers) | 93.3 | 7.7 |
| The fact that average user does not have technical knowledge | 100 | 0 |
| Learners' activity tracking | 86.7 | 13.3 |
| Debugging functionalities | 73.3 | 26.7 |

[32] The majority of the participants had worked with the ReCourse LD editor and the Astro LD player.

### 7.4.2 Requirements prioritization through the use of Qualitative Comparative Analysis

In the QCA used here, the outcome (i.e. dependent) variable was "Expectations" whereas the causal conditions (i.e. the independent variables) were the ones associated with the questions above: "help", "visualization",…., "debugging". Also, the values of the outcome variable correspond to the values of the participants answers in the statement "To what extent does the proposed design solution meet your expectations?", which was included in the evaluation questionnaire. That is, the model suggested by the QCA is the function: expectations = f(help,…, debugging).

Using Crisp sets (csQCA): In the preparation phase, the values 0, 1,2, 3 were coded as 0, whereas the values 4, 5 were coded as 1. In significance order, associations exist between the variable "expectations" with the variables "visualization", "help", "reduced complexity", "collaboration", "familiarization", "richness", "adaptation", "changes", "average user", "tracking" and "debugging" as revealed by crosstabulations (see Annex 3). In running the Crisp Truth table algorithm, "expectations" was set as outcome and the remaining variables were set as causal conditions. The truth table output suggested that the most suitable solution is

Expectations = changes*adaptation*averageuser*richness*reducedcomplexity*collaboration*familiarisation*visualisation*help,

With raw consistency = 0.571429, unique coverage = 0.5 and consistency = 1.

The raw coverage of the solution is the extent to which the specific solution can explain the outcome (not only one solution exists, here we have seven solutions; see Annex 4). The unique coverage is the proportion of cases that can be explained exclusively by that solution. If consistency score is below 1.0, this means that the solution covers one or more cases that do not display the outcome; i.e., they deviate from the general pattern found in the data. The lower a consistency score, the more cases do not fit the patterns identified by QCA, or the more substantial are the contradictions that certain cases pose.

On the one hand, the solution suggests that the presence of debugging or user tracking functionalities in an envisioned system for adaptive learning is not necessary or sufficient conditions for meeting the users' expectations. On the other hand, 1) enhanced functionality in making changes in an existing unit of learning, 2) system adaptation, 3) taking into account that the average user does not have technical knowledge, 4) authoring of “rich” adaptive learning designs, 5) reduced complexity in the authoring process, 6) collaboration (computer supported collaborative design), 7) Windows-like or/and microsoft-like environment (i.e. look and feel that is familiar to the end users), 8) visualised Learning Design and 9) user help are, at a great extent, sufficient and necessary conditions in meeting users’ expectations.

Using fuzzy sets (MVQCA /fsQCA): In this case, the values 1, 2, 3, 4 and 5 of the 5-point Likert scale used in the questionnaire were coded as 0.2, 0.4, 0.6, 0.8 and 1 respectively. Surprisingly, the use of fuzzy sets was not proved more suitable for the data analysis, since the application of the Fuzzy truth table algorithm in the fuzzy sets revealed solutions with significantly lower levels of accuracy and coverage, compared to those derived from the application of the Crisp Truth Table Algorithm to crisp sets, as described above.

### 74.3 Participants’ comments in the open –ended question of the evaluation questionnaire

The majority of the participants expressed their views on the design through an open ended question (“would you like to add anything else concerning the proposed design solution?”) at the end of the evaluation questionnaire. Comments and suggestions by the respondents include the following (n=10):

- Two respondents commented that the design resembles an envisioned version of LAMS for rich adaptivity.
- Two respondents commended that it was a nice effort, combing many useful characteristics in a user-friendly environment.
- Two respondents commended that the design seems very interesting as a design solution, but in order to have a clearer view they need to experiment with a fully functional prototype.

Other suggestions or advice coming from the participants include the following:

- Make the design more accessible for users with special needs.
- Include more interactive scaffolds, like a note –taking tool.
- More work is needed in the design in terms of User Experience.

- The work of the end user should be saved automatically if the user presses the close button.
- The logo which identifies the ownership of the system is missing.

## 7.5 Discussion

The proposed design solution extends the idea of "teachers as designers" (Bers, Ponte, Juelich, Viera, & Schenker, 2002; Yoon, Ho & Hedberg, 2006; Mavroudi & Hadzilacos, 2013) in the case of adaptive learning environments, while coping with problems and addressing needs mentioned in the bibliography, like:

- teachers need tools that enable them to make adjustments to existing Units of Learning, such as "changing the learning resources or choosing between alternative activities" (Griffiths & Blat, 2005)
- "many teachers and learning providers from contexts where UOLs are not developed entirely by technical experts are also interested in LD" (Griffiths & Blat, 2005, p.2)
- "create a cut down version of UML, containing only the parts needed to represent UOLs" (Griffiths & Blat, 2005, p.2)
- the representation of the organization should not hide the sequence of events (Griffiths & Blat, 2005)
- computer supported collaborative design can foster the concept of seeing teachers as designers (Mavroudi &Hadzilacos, 2013).

On top of that, the proposed design addresses satisfactorily the needs mentioned by the research participants such as: reduced complexity, look and feel that is familiar to them and adaptation of the system itself in order to provide personalized functionality and services. Design principles of a user-friendly digital environment for adaptive learning were produced and prioritised. For the scope of the work, they constitute necessary and sufficient conditions to keep the end users satisfied at the completion of the design process. The use of QCA method, a method originally derived from social sciences, was proved efficient in the data analysis process. Through its exploitation, the eleven design principles originally identified were reduced by two, thus highlighting the most crucial ones. This process might enable the development team to prioritise the requirements in a user-centred way. In times of economic crisis, where resources are scarce this is even more important.

Finally, the combined results from tables 18 and 19 provide some conclusions about the relative effectiveness of the proposed design solution concerning the above parameters. It seems that the Debugging issue was not as effectively tackled as the other key considerations. This is less true for the Learners' activity tracking issue.

Instructional designers need to be involved in the development of adaptive learning systems with system developers. It is important to note that adaptive learning environments should not be developed for a specific domain or subject matter. On the contrary, adaptive elearning systems should enable teachers or instructors to integrate a variety of pedagogical devices learning contents and collaboration strategies into the system to improve their uses in education. Consistent with this view, Chieu (2005) points out that adaptive elearning systems should be domain independent (Kara & Sevim,2013).Finally, it has already been discussed in paragraph 1.2 that the absence of theoretical or methodological frameworks hinders the effectiveness of adaptive instruction. To compensate for this , as it has been mentioned in the beginning of this chapter, the design of the sub-system who is responsible for the creation of the adaptive e-courses by the end users (teachers, instructional designers etc) is influenced by the theoretical frameworks mentioned in Chapter 3. This is explained in detail in the next chapter.

## 7.6 Annexes

**Annex 1: PDR meeting agenda – walkthrough methodology**

1. Question: Is each requirement relevant to the problem and its solution?
2. Question: Is the requirements document clearly and logically organized?
3. Question: Are any of the requirements redundant?
4. Question: Are there any ambiguous requirements that could be interpreted in more than one way?
5. Question: Are the requirements specified at the right level of detail? (Are any of the requirements too detailed, or not detailed enough? )

6. Question: Are any of the defined requirements really design or project management details?
7. Task: Identify areas where the design concept might not work. Please explain why. For those areas could you suggest an alternative approach?
8. Question: What is the impact to the potential users?
9. Question: What critical problems does this design solve? Are there any critical problems not solved with this designed approach?

**Annex 2: Concepts and codes emerged after the application of the Grounded Theory**

Integration with external tools/services

- Widgets/e-learning services
- External educational repositories
- Youtube and similar services
- Export your scenario to an external platform

Metadata indexing

- Easy authoring
- Easy search

Scenario authoring

- Structure of a learning scenario
- Adaptive and non-adaptive mode
- Scenario composition

Synchronous (real-time) and asynchronous communication

- Chat, Forum, email

- Interaction between stakeholders in real-time
- Computer Supported Collaborative Design

User-friendliness and learnability

- transparent (no need to write or understand code or pseudo-code)/ enhanced visualization
- smart environment/recommender system elements/personalized UI (based on the user traits)
- easy to add or delete elements from the learning scenario
- flexible: easy to make changes
- No technical knowledge required to operate it/graphical UI
- Microsoft office-like and windows functionalities (drop-down menus, drag-n-drop, copy, cut, paste etc)

Localisation

- Avoid technical terminology
- Translation (i.e translated UI or multilingualism)

# Annex 3: Cross-tabulations

| N expectations | help 0 | help 1 | |
|---|---|---|---|
| 1 | 1 | 13 | 14 |
| 0 | 0 | 1 | 1 |
| | 1 | 14 | |
| Total N | 15 | | |
| Missing | 0 | | |

| N expectations | visualisation 0 | visualisation 1 | |
|---|---|---|---|
| 1 | 0 | 14 | 14 |
| 0 | 1 | 0 | 1 |
| | 1 | 14 | |
| Total N | 15 | | |
| Missing | 0 | | |

| N expectations | richness 0 | richness 1 | |
|---|---|---|---|
| 1 | 1 | 13 | 14 |
| 0 | 1 | 0 | 1 |
| | 2 | 13 | |
| Total N | 15 | | |
| Missing | 0 | | |

N

| expectations | tracking 0 | tracking 1 | |
|---|---|---|---|
| 1 | 5 | 9 | 14 |
| 0 | 1 | 0 | 1 |
| | 6 | 9 | |
| Total N | 15 | | |
| Missing | 0 | | |

N

| expectations | averageuser 0 | averageuser 1 | |
|---|---|---|---|
| 1 | 4 | 10 | 14 |
| 0 | 1 | 0 | 1 |
| | 5 | 10 | |
| Total N | 15 | | |
| Missing | 0 | | |

N

| expectations | familiarisation 0 | familiarisation 1 | |
|---|---|---|---|
| 1 | 2 | 12 | 14 |
| 0 | 1 | 0 | 1 |
| | 3 | 12 | |
| Total N | 15 | | |
| Missing | 0 | | |

N

| expectations | collaboration 0 | collaboration 1 | |
|---|---|---|---|
| 1 | 2 | 12 | 14 |
| 0 | 1 | 0 | 1 |
| | 3 | 12 | |
| Total N | 15 | | |
| Missing | 0 | | |

N

| expectations | reducedcomplexi 0 | reducedcomplexi 1 | |
|---|---|---|---|
| 1 | 1 | 13 | 14 |
| 0 | 1 | 0 | 1 |
| | 2 | 13 | |
| Total N | 15 | | |
| Missing | 0 | | |

```
                |adaptation
expectations    |        0 |        1 |
----------------+----------+----------+
1               |        0 |       14 |       14
----------------+----------+----------+
0               |        1 |        0 |        1
----------------+----------+----------+
                         1         14
Total N                 15
Missing                  0

N               |
                |changes
expectations    |        0 |        1 |
----------------+----------+----------+
1               |        1 |       13 |       14
----------------+----------+----------+
0               |        1 |        0 |        1
----------------+----------+----------+
                         2         13
Total N                 15
Missing                  0
```

## Annex 4: csQCA - Truth table analysis

Model: expectations= f (changes, adaptation, averageuser, tracking, richness, reducedcomplexity, collaboration, familiarization, visualization, help, debugging)

Rows: 11

Algorithm: Quine-McCluskey

True: 1

0 Martix: -CL

--TRUTH TABLE SOLUTION—

frequency cutoff: 1.000000

consistency cutoff: 1.000000

Assumptions:

**Table 27 Truth table solution**

| | raw coverage | unique coverage | consistency |
|---|---|---|---|
| changes*adaptation*averageuser*richness* reducedcomplexi*collaboration*familiarisation* visualization*help | 0.571429 | 0.500000 | 1.000000 |
| changes*adaptation*averageuser*~tracking* *richness*reducedcomplexi*collaboration* visualisation*help*debugging | 0.142857 | 0.071429 | 1.000000 |
| changes*adaptation*averageuser*~tracking* *richness*reducedcomplexi*~collaboration* familiarisation*visualisation*~help*~debugging | 0.071429 | 0.071429 | 1.000000 |
| changes*adaptation*~averageuser*~tracking* *richness*reducedcomplexi*collaboration* familiarisation*visualisation*help*~debugging | 0.071429 | 0.071429 | 1.000000 |
| ~changes*adaptation*~averageuser*tracking* *richness*reducedcomplexi*collaboration* familiarisation*visualisation*help*~debugging | 0.071429 | 0.071429 | 1.000000 |
| changes*adaptation*~averageuser*tracking* *~richness*reducedcomplexi*collaboration* ~familiarisation*visualisation*help*debugging | 0.071429 | 0.071429 | 1.000000 |
| changes*adaptation*~averageuser*tracking* *richness*~reducedcomplexi*collaboration* familiarisation*visualisation*help*debugging | 0.071429 | 0.071429 | 1.000000 |

Solution coverage = 1.000000

Solution consistency = 1.000000

## Annex 5. The UI mockups along with the accompanying descriptive texts

It should be noted that none of the User Interfaces are screenshots depicting the functionality of already existing tools.

### Login-Profile

The user can login by completing the dedicated form either online (through the web-based version of the system) or via the local instance of the system. After the completion of the login process, the corresponding tables (the tables that are related to the user profile) in the system database are updated. Next, based on the user choices, the system (due to its adaptivity) creates recommendations and presents them to the user. For example, the system may recommend scenarios or activities or learning materials that are in accordance with the teacher's expertise. The system, based on the teacher profile and her choices continuously updates and builds her profile.

For security prurposes, in the login process exists a security check via CAPTCHA. Alternatively, the educator can register in the system using the registration data coming from one of her email account, like yahoo or gmail.


Figure 30 UI mockup-Login

After her registration, the educator may wish to declare some more information about herself in order to better inform her profile. This is not a mandatory action, its aim is to help the system initialise better her profile in order to provide personalised/customised services to her (they are described in various points in this text). Provided that she decides to declare that extra information about herself, she declares her expertise (educator? Instructional designer? Researcher? Software engineer? Other? If she is an educator, what is her domain expertise?), language preference, and whether she allows or not the system to conncet with her profile in social networks (like Facebook and Twitter) and harvest information about her. If she agrees with the latter option, she can select the social network(s) by clicking on the respective icon(s) shown in the figure below.

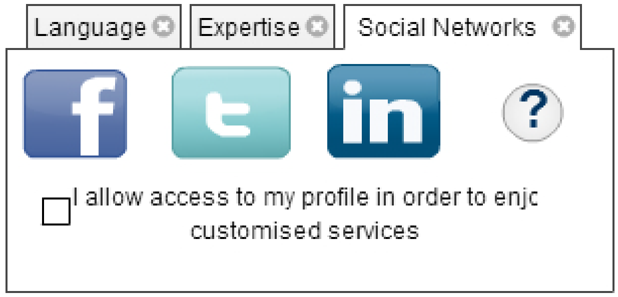



Figure 31 UI mockup-Profile settings

**Welcome screen**

The UI of the digital environement is multilingual. In the upper right side of the screen there is a UI element though which the user can customise her language preference. Also, in the rightmost corner of the screen there is a button where the user can customise the background colour. In the bottom of each screen, at the right side, the user can click the help icon, in order to receive asynchronous or synchronous (live) help.

The first time the educator logs in to the system, the rightmost (backpack) of the three images (library, scenarios,backpack) may not be visible, since the backpack is empty. There are two possibilities for the first time the user logs in the system: either to see a completed lesson/scenario (library icon) or to start creating her own scenario (scenario icon). If it is not the first time that the user logs in, the backpack icon might be also visible.

In case the user clicks the backpack icon and it is empty, a message appears in the screen. For example, it could be: “You don’t have anything in your backpack yet”, or “Your backpack is empty”.

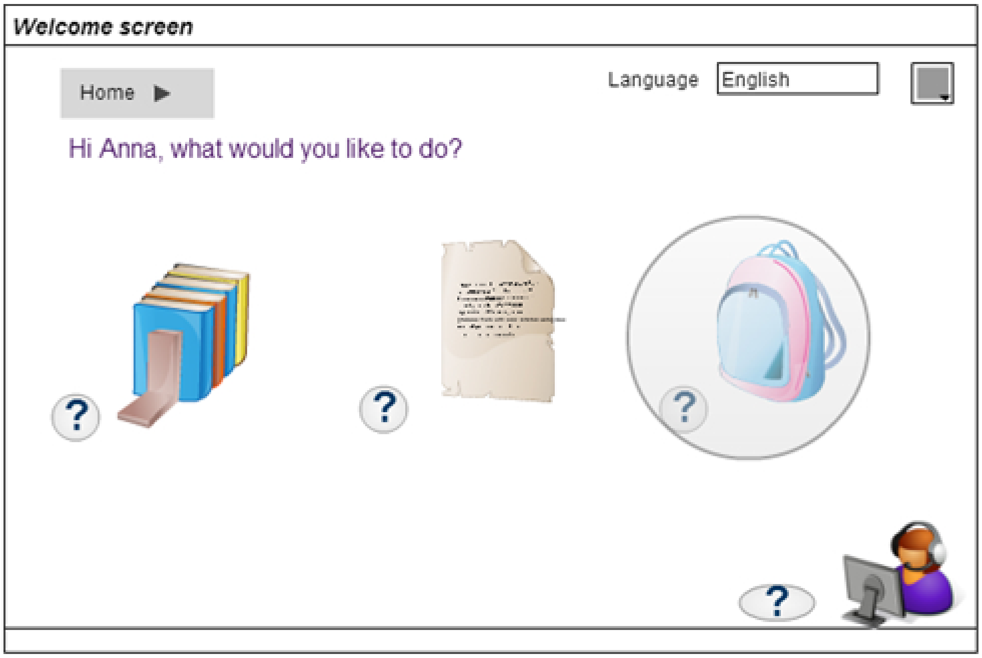



Figure 32 UI mockup-Welcome screen

**Scenario creation**

Initially the teacher completes the basic elements of the scenario using a dedicated form (acordeon type). The questionmarks depicted in the figure below and in other figures in this section play a supportive role. Similarly to moodle, when the user clicks such a questionmark, a small explanatory text appears in a pop up window. The words "title", "prerequisite knowledge" etc. are accompanied with visual clues/icons, whenever possible. In each space (e.g. webpage) of the digital environment , the navigation is possible through breadcrumbs[33].

In a second phase, the teacher indicates the basic structure of the scenario. Intitially, she decides whether she will use a template. If the user is novice the system suggests the use of a template. The choice "select template…" appears only after the user clicks in the corresponding icon depicted in the right side of the screen. This enables the user to select a specific type of template,

[33] http://en.wikipedia.org/wiki/Breadcrumb_(navigation)

like a template for collaborative learning, for problem solving, for experiential learning, for exploratory learning, a custom-made template created by another user or by the user herself etc.

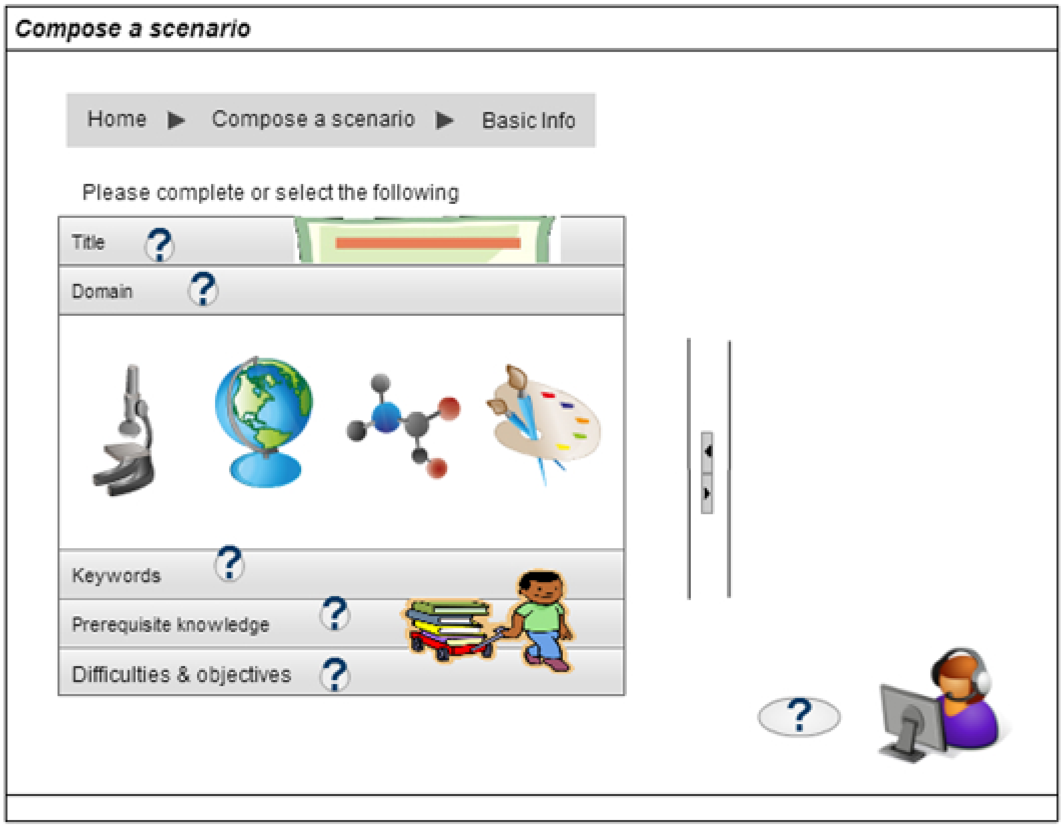



Figure 33 UI mockup-Lesson authoring–basic metadata

Next, the user sees the environment in which she will synthesize her pedagogical scenario.

The scenario phases are created in the previous phase either automatically (in case the user selects a specific template) or manually by the user (in case she wishes to take control of the process by creating- using drag'n drop- her group, assign roles and create the conditions).

In this subsystem, in the right side of the screen the user can see the communication and collaboration tools. More specifically (starting from the top of the right side of the screen): the user forum, the live chat, the VoiP (skype) functionality, "invite" functionality (Computer Supported Collaborative Design-CSCD), the sharing functionality and user help. The user can receive immediate/synchronous help and support through live chat with a human agent, in case the latter is online. Also, the user can receive asynchronous support by pressing the questionmark icon, something that will direct her in the help page.

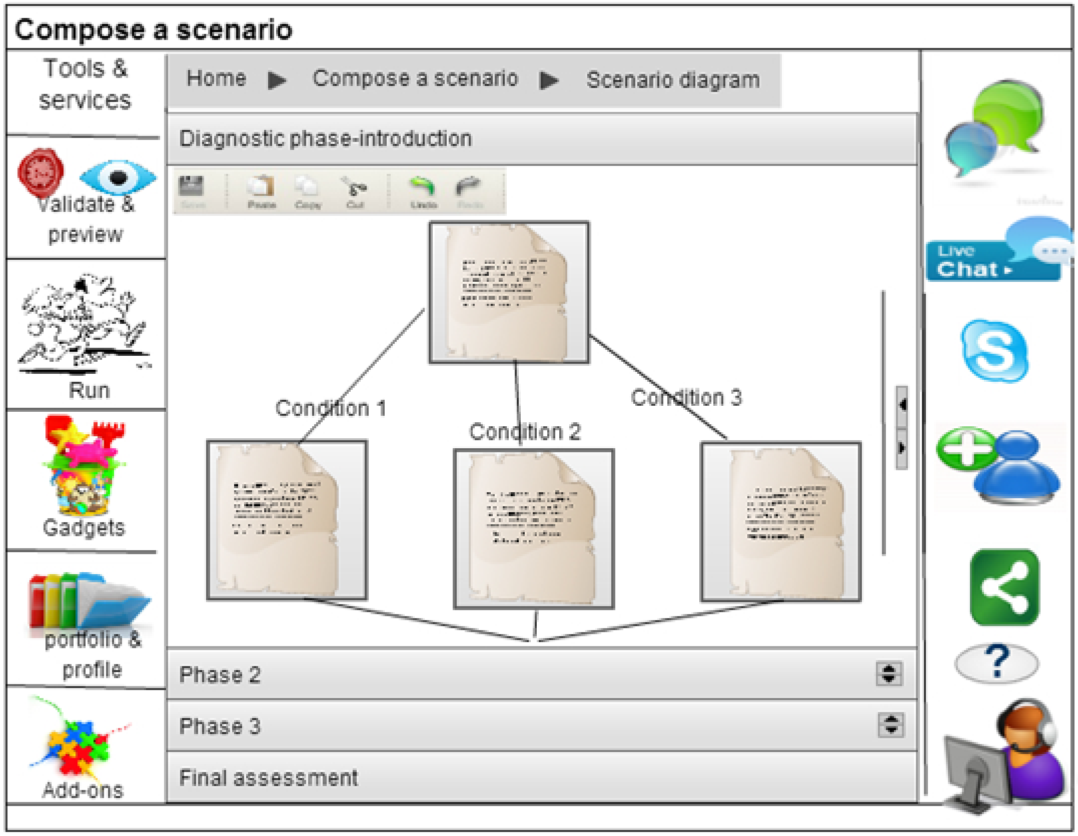



Figure 34 UI mockup-Authoring the adaptive learning lesson (lesson diagram)

In relation to the "invite" functionality: the primary author invites for scenario co-design other persons (secondary authors) by sending a dedicated and unique URL through which they can have access and/or editing rights in the scenario. (This functionality is similar to the Google drive collaborative document editing functionality.) This is how CSCD can be enabled.

The main part of the screen is the workspace. A cut-down, simplified version of UML is used for the representation of the adaptive learning scenario. The user can perform the typical Windows functionalities, like: copy, paste, cut, save, undo, redo. Also, the user can move the various phases of the scenario if she wishes in order to change their sequence. In case one of these actions violates one or more of the scenario conditions, the system presents to the user the corresponding message explaining why the specific user action is not possible and/or suggesting alternative solutions.

Furthemore, depending on the user profile (novice or advanced user), the system may present one or more adaptation parameters to the user, since it is known that the complexity of an adaptive learning scenario increases as the number of adaptation parameters increases.

Let's assume that the user wishes to exploit two adaptation parameters in the same phase of the scenario. For example, the adaptation parameters are: student prior knowledge with three levels (mediocre, good and very good prior knowledge) and learning style with four categories (visual, aural, read/wirte, multimodal). Then, the system prompts a message to warn the user that in the next phase of the scenario twelve (3*4) different versions will have to be deifned by her. The system, must discourage the user from doing so, if she is novice. Or, alternatively, to reduce the complexity, for example, the system proposes to the user to define two levels of prior knowledge (instead of three levels).

In the left column of the screen there are icons for tools and services concerning either the scenario as a whole (i.e. validate), or a certain point of the scenarion (i.e the user wishes to add widgets/gadgets as part of a learning activity).

The difference between gadgets and add-ons is that the former relate to standalone applets (like, a translator or applets like the ones available here http://www.google.com/ig/directory?synd=open) whereas add-ons relate to additional built-in functionality (like, powerpoint viewer or flash player etc).

Next, the user selects the individual scenario parameters, the roles and indicates whether the scenario is adaptive or not. The icons that correspond to parameters and methods appear conditionally, that is, they appear if the user denotes that the scenario would be adaptive. The system, due to the fact that it is smart, presents some predefined choices in order to guide the user.

For example, if the user is about to deal with the diagnostic phase of the scenario the system deactivates the 'student progress' adaptation parameter, provided that the diagnostic phase takes place at the beginning of a scenario.

Also, if the user selects learning style (aural, visual etc type of learner) as adaptation parameter the system creates mappings between the learning style preference and the types of activities (in order to facilitate the differentiated content presentation). Consequently, the system can recommend specific learning objects for each type of learner to the educator.

This is feasible if the system harvest the metadata accompanying the learning resources that reside to other locations. For example, the “Photodentro” repository categorises its learning resources using several ways. In the “learning object type” categorisation there is one category titled “images”. This category could be associated with the visual type of learner. In tandem with the information coming from the user profile (for example, expertise) and the keywords that the user has already written in the previous phase of the scenario the system could make relevant associations and reccommendations to the user. The reccomendations will involve relevant learning resources.

Finally, there is a history log of the changes that happended in the scenario (similar to the tab ‘History’ that exist in the wikis) in order to see who has made each change. The primary author of a scenario can select a specific change and undo that change if she doesn’t agree with it.

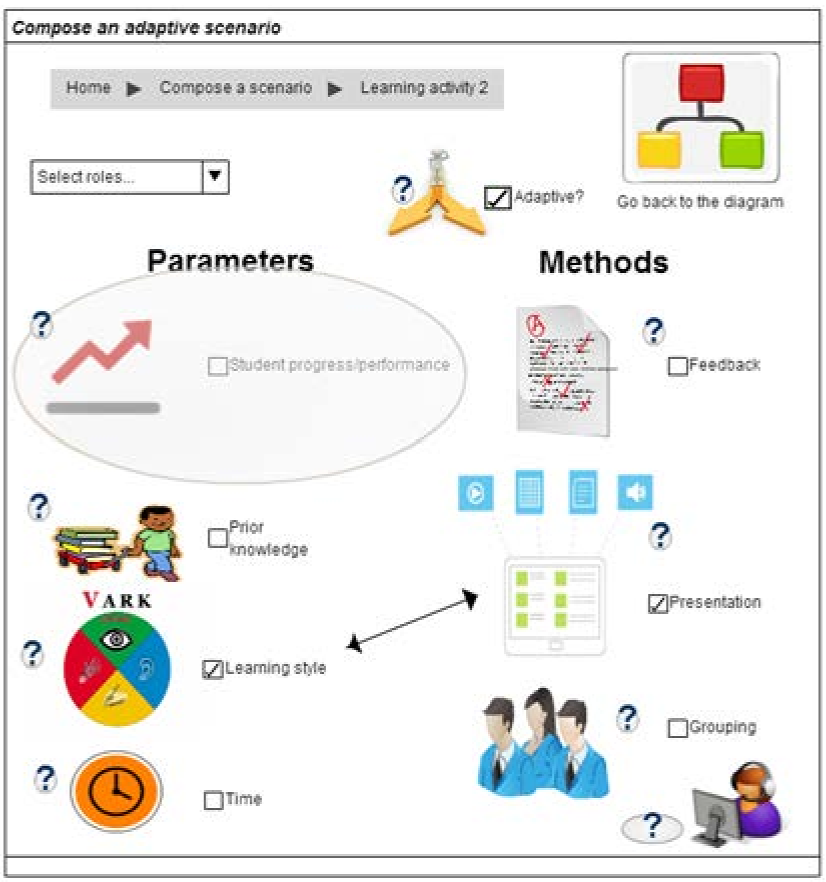



Figure 35 UI mockup- Lesson authoring – learning activity creation

Then, the user defines the basic elements of an activity and next she selects the accompaying content and learning tools. The user can add resources and  tools or search for them. On behalf of the system, the reccomendations mentioned above apply.


**Figure 36 UI mockup-Lesson creation – learning activity customisation**

## Help

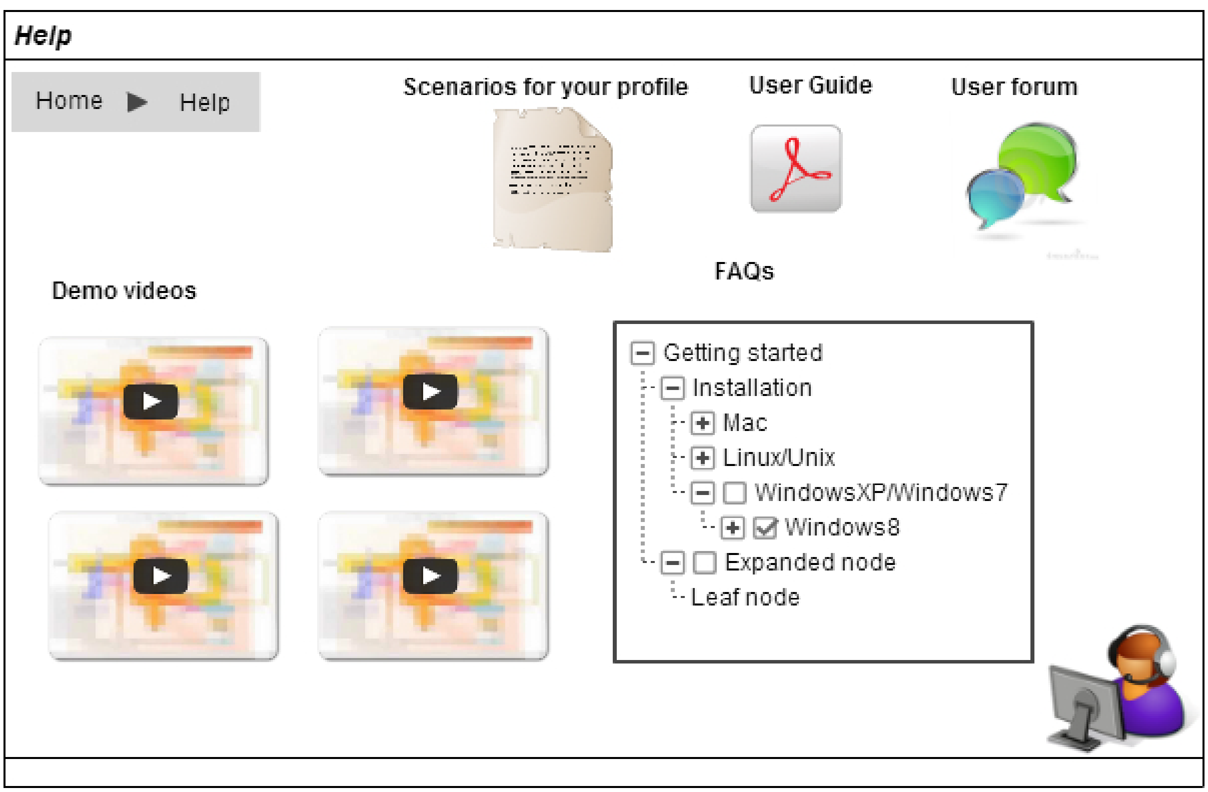


Figure 37 UI mockup- Help

The help page contains:

- a series of informative demo videos
- a series of Frequenlty Asked Questions (FAQs)
- the user forum (where users can ask questions and discuss asynchronousy)
- worked-out scenarios that match the user profile
- the complete user guide

**Personal page**

The personal page of the user contains:

- her semi-completed scenarios (primary or secondary author)
- the worked-out scenarios (her own scenarios or those she bookmarked),
- the list of her friends (invite functionality),
- the email functionality (send and receive email messages)
- the learning analytics dashboard (where she can see in a visualized way her students' progress and their interactions with the system)


Figure 38 UI mockup-My profile page

**Search**

Search can be simple or advanced (like in every search machine), but also it can be enabled through tag clouds. The relative size of the tag indicates the number of the scenarios or the number of the activities associated (tagged) with the specific keyword. The tags are in line with the profile of the teacher. For example, to a teacher whose interests are close to computer science and mathematics, a cloud similar to that depicted in the figure below may appear. In that case, the tag cloud would be associated with mathematics scenarios or Informatics scenarios or cross-curricular scenarios.

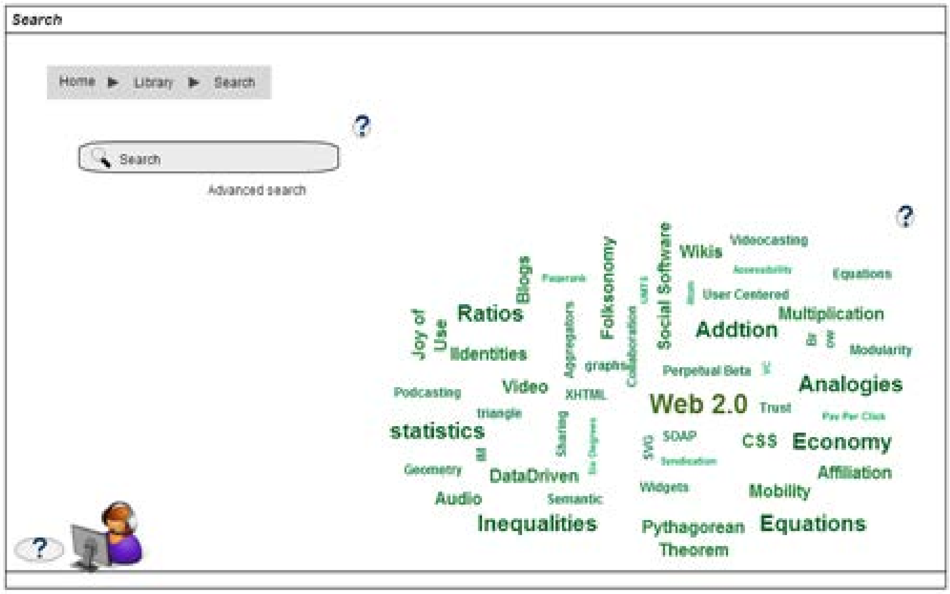



Figure 39 UI mockup-Search

**The player**

(Note: this sub-system is not exclusively design for children)

In the right side of the screen you can see the workspace where the activities are visible (content and learning tools). In the left side of the screen the student can inspect their learning path (the sequence of previous activities up to the current one). Students, especially younger ones, need to feel that they have control over the digital environment they work with. Thus, after discussions with students, the following functionalities were addred to the design of the UI:

- Background and font customisation (maybe conditionally activated or with a limited number of possible changes in order to prevent students' distraction, that is, to discourage students from continuously experimenting with background and font)
- Print screen
- Full screen
- Timer (conditional appearance, for exaple through mouserover )

- Drag’n’drop prior and current activites in the workspace (in order to open them or initialise them, respectively)

Typical usage scenario of the player

Andrew follows the lesson “Communication protocols” through his computer. In the beginning of the lesson he learnt what WWW is, then what Internet is and now he is trying to understand the differences and the similarities between them.

Andrew and his classmate, Maria, don’t follow the exact same lesson, since they don’t have to complete the exact same activities or to solve the same problems. For each student this digital environment presents somewhat different activities, depending on how he answered in the previous questions, whether he is an aural or a visual type of learner, whether he likes to work and learn collaboratively or to work on his own. He has five minutes left, the timer is activated (moving image or alarm or both). This doesn’t make him anxious, since he can continue his work back at home or in the school (the next time).

Above the envelope icon, in the left side of the screen, he notices an indicator of a new unread email message. It should be probably from Mr. Yiannos, his teacher in the Informatics course. For whom is this message addressed? Him, his classmates or his group? From the title of the message (visible above the envelope icon) he understands that this message probably relates to to the Informatics course and, thus, he decides to open it.

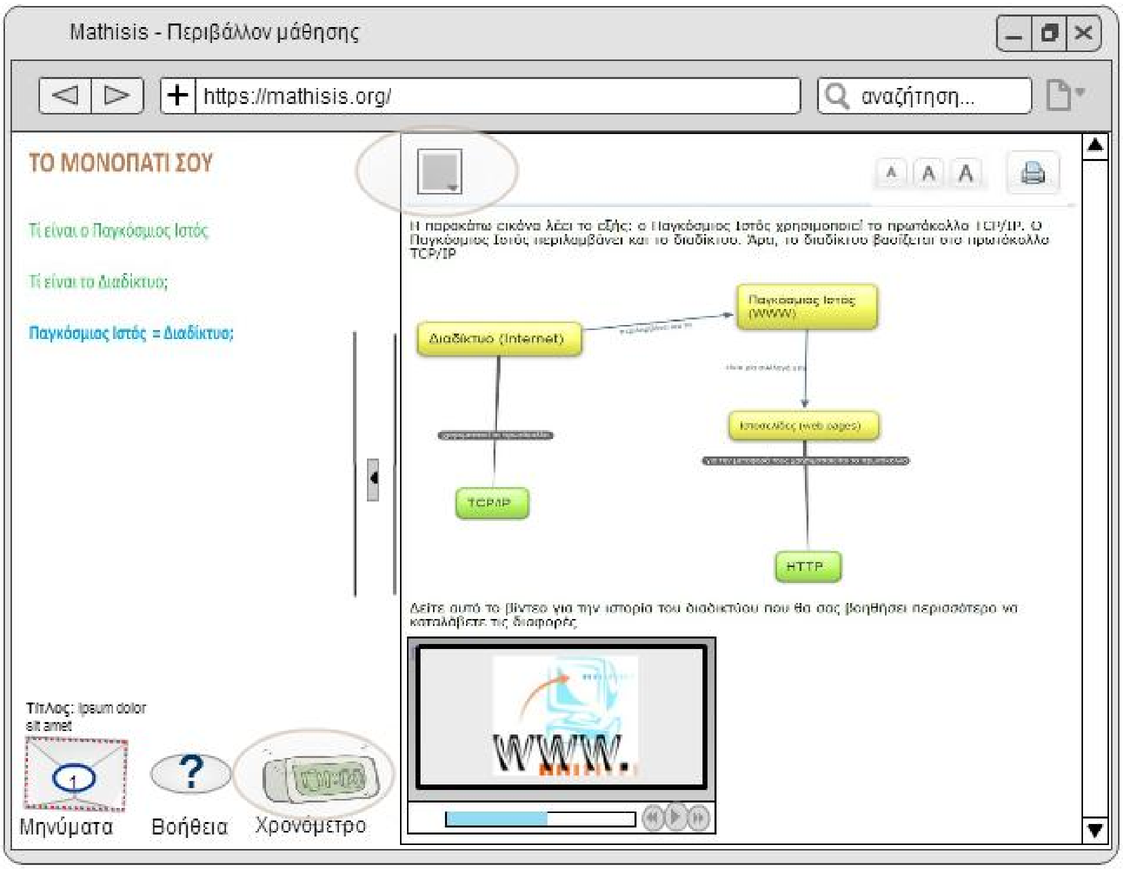



Figure 40 UI mockup-The player of the proposed system

## Annex 6: The assignment concerning the scenario of the envisioned system for adaptive learning

In your previous projects, you learnt how to design Units of Learning using the Learning Design standard along with two tools: the ReCourse LD editor (as an authoring tool) and the Astro LD player. At the end of your assignments you were called to reflect on your experience and comment on the tools, the LD and the entire project process. Some of you wrote that you would prefer other tools. Looking back on your answers describe with 200-300 words how you would fancy an environment with ideal characteristics and functionality? Could you describe it as a visionary scenario of use?

Example

A scenario of an ideal web search environment might look like this:

"Andreas, a musician from Latsia, just bought a laptop with pre-installed Windows 8. For any new item, Andreas firstly informs himself about its functionalities and later on, he tests them. Thus, he is ready to search the WWW for information about Windows 8. He opens his old computer and enters the address www.google.com in his browser. Automatically he is being redirected to his personal page on iGoogle.  On this page, he can see: the Google search engine (in the center of the screen), the list of his pending tasks/TO-DO list (on the right side of the screen), a preview of his latest email messages as well as a contact list comprised with contacts which are linked with his gmail account and, at the same time, are available online via chat.

Andreas writes «ςινδοςς 8» instead of "windows 8" (he didn't notice that he was typing Greek characters). However, the results shown in the first pages are all about Windows 8.  Andreas inspects the list of the search results shown on the first page. Judging from the title, the short description and the type of the file (youtube video, text in pdf, html pages etc), he tries to figure out which results might be more suitable and relevant for him.  Just beneath the search engine field, the known search options of the horizontal menu are displayed ("Web", "images", "Maps", "More…") but there is also one option which he notices for the first time named "Applications". He clicks on the word "Applications" and he sees a list of results associated with Windows 8 applications.  At that time, he sees a chat message coming from Maria saying "How do you like Windows 8? Try the Piano time application, you'll like it!". Andreas, thinking that the synchronization with Maria is a happy coincidence and knowing that she has been working with Windows 8 for a long time now, decides to try her suggestion.

No need to explain that there are no wrong or right answers, but there are more or less creative answers!

**Annex 7: The use cases (in their final form)**

**Use case 1: System Installation**

Primary actor(s): Teacher, Instructional designer

Summary: Teacher installs the system.

Main success scenario: The teacher wants to install the system in her laptop, which uses Windows8 as an operating system. In the download webpage, she can see the Windows version, the Mac version and the Unix version of the system. She selects the Windows version and then she downloads and runs the executable installation file. The installation is straightforward, she only needs to declare the location where the system will reside. The installation is completed.

Alternate scenario: The teacher doesn't wish to install locally the system, but prefers to use its web-based version.

Prerequisites: Internet connection

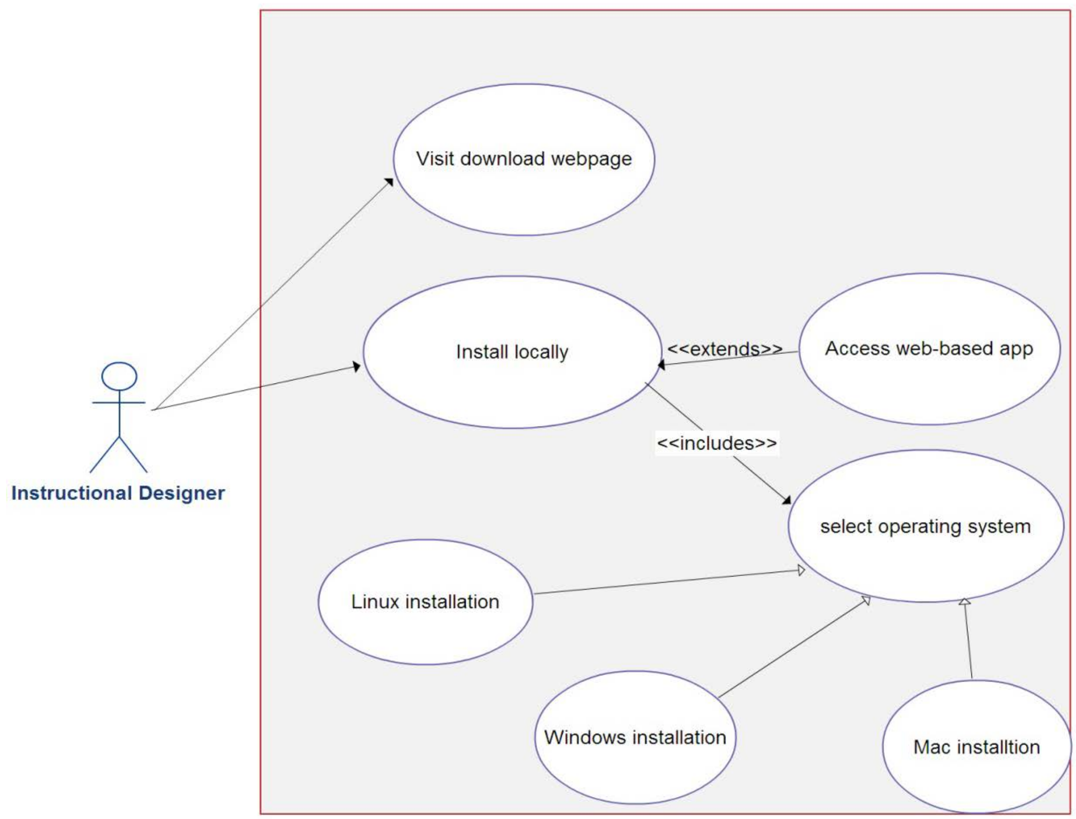



**Figure 41 use case 1 diagram**

**Use case 2: Registration**

Primary actor(s): Teacher, Instructional designer (in general)

Summary: The teacher registers herself

Main success scenario: The teachers double clicks the system icon on her desktop. The application is launched for the first time and asks the teacher to fill in the registration form (First name, Last name, email, username, password). After completing this action, the teacher logs into the system and she sees the welcome screen. The personal data and contact details of the teachers are inserted into the system.

Alternate scenario: If the system uses the web-based version of the system, she types the URL through which the system is accessible. Then she can complete the Registration form online.

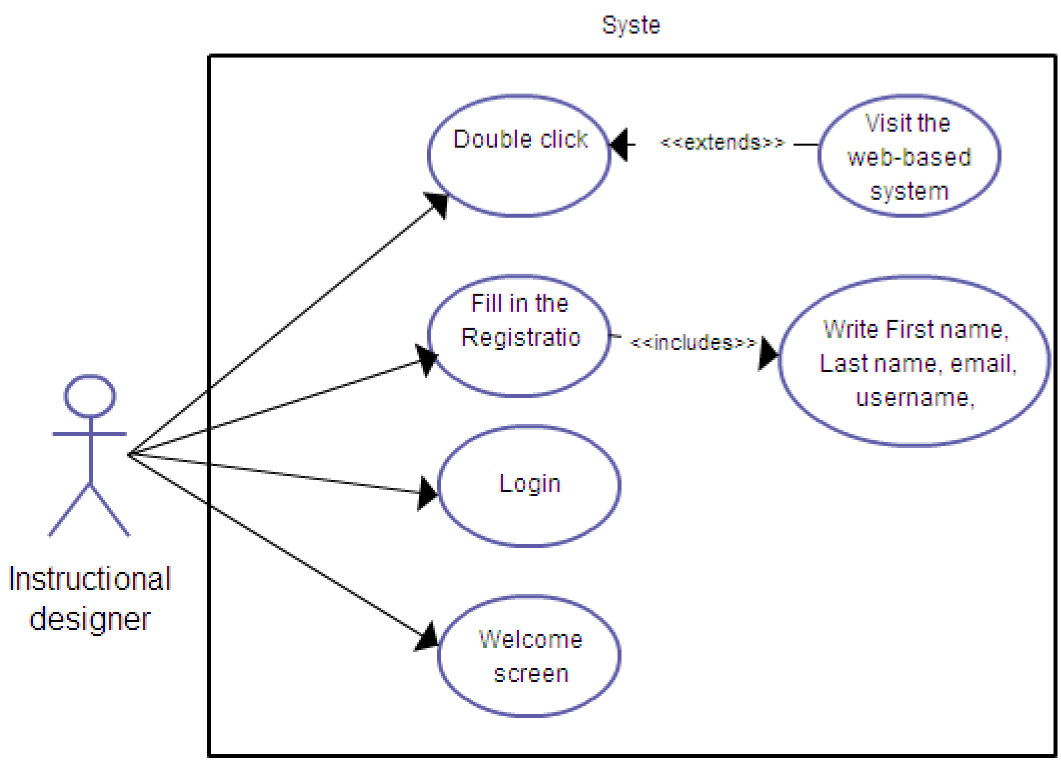



Figure 42 Use case 2 diagram

Note: All the subsequent use cases have use cases 1 & 2 as prerequisites.

**Use case 3: Welcome screen options**

Primary actor(s): Teacher, Instructional designer (in general)

Summary: The first choices the teacher can make when she logs into the system for the first time. Main success scenario: The teacher logs in with her credentials and sees in her screen the following options:

1. Author a new scenario, 2. Find an existing scenario

Alternate scenario (for the subsequent times the teacher logs into the system): The system checks whether the teacher has already drafted any scenario. If yes, the teacher can see an extra option titled "My scenarios", where she can access all her unfinished or completed scenarios. If no, the main success scenario is implemented.

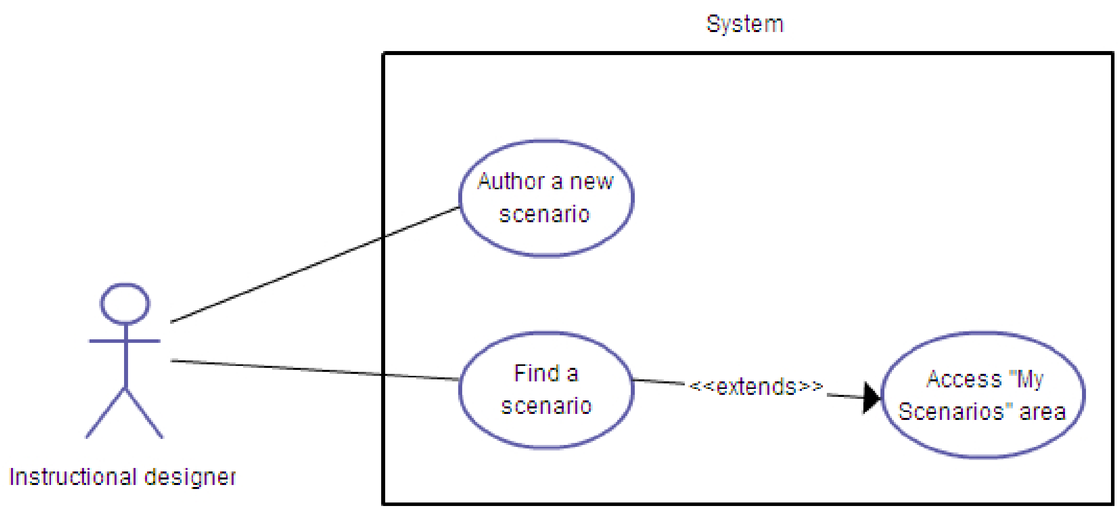



**Figure 43 Use case 3 diagram**

**Use case 4: Compose a scenario/create an e-course**

Primary actor: Teacher, Instructional designer (in general)

Summary: The teacher authors a scenario

Main success scenario:The teacher completes the main metadata of the scenario: Title, grade, topic/domain, prerequisites. Then she is prompted by the system to declare whether her scenario would be adaptive or not. If her scenario is adaptive, then system activates the subsystem through which she can define the adaptation rules/strategy. In each phase of the adaptive scenario, the teacher is presented with the available adaptation methods. She can choose one or more among the following:

- adaptive content presentation -the changes of the actual content
- adaptive user grouping,
- adaptive evaluation- changes based on learner's performance
- problem solving support –guidance/feedback that helps the user to take a step further in solving a problem
- adaptive learning flow -the sequence of the learning activities

and the available adaptation parameters

- learning style
- learning objectives
- student performance
- time availability
- prior knowledge.

The teacher decides the adaptive learning strategy and semi-automatically completes her scenario. The system based on her decisions about the adaptation methods and adaptation parameters and taking into account the metadata about the content and the data about the student profile, guides the teacher to complete the structure of her scenario. This could be feasible through a questions-answers dialectic, interactive process between the system and the teacher. The final result is a dataflow diagram that depicts the structure of a scenario and can be automatically converted to a pedagogical scenario. Since it is an adaptive learning scenario, the respective dataflow diagram it has more than one swimlanes. If the scenario is non-adaptive, then a linear learning path is assumed and the dataflow diagram has only one swimlane. After the structure is completed, the teacher focuses in each of the structural element. When the teacher points to a structural element, the system provides a dedicated graphical UI where the teacher can configure it. Also, the system may recommend content, activities, phases, services and scenarios based on their accompanying metadata, the teacher profile and contextualised user ratings. For example, recommendations are provided so that the domain (as a teacher profile parameter) is mapped with the domain/topic of the scenario to be authored (as a scenario metadata). Or, so that the prerequisites (as a scenario metadata) are mapped with student's prior knowledge (as a student profile parameter). Another example: the system may recommend scenario templates or, equivalently, dataflow diagrams based on the adaptation strategy selected by the teacher.

<u>Prerequisite requirement(s):</u> use cases 7 & 9

<u>Prerequisites:</u> Internet connection (in order to receive recommendations)

<u>Non-functional requirement</u>: The dedicated graphical UI should support visualised LD.

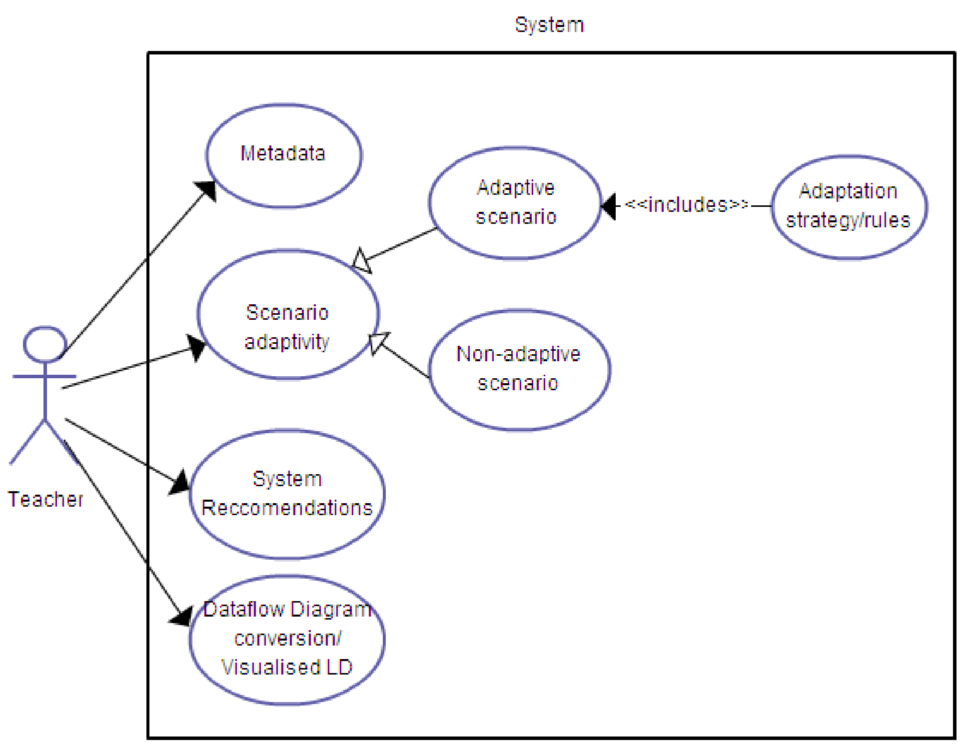



**Figure 44 Use case 4 diagram**

<u>Importance</u>: The transparency principle and the visualised Learning Design principle are highly important, especially in the case of designing adaptive e-courses. For example, in the case of adaptive scenario the teacher can choose from drop down lists the adaptation methods and the

adaptation parameters. The conversion of the pedagogical scenario form to a dataflow diagram of the adaptive course is automatically implemented by the system.

**Use case 5: Test run the scenario/e-course**

Primary actor(s): Teacher, Instructional designer (in general)

Summary: The teacher validates and previews her scenario

Main success scenario: The teacher frequently validates, tests/controls and previews her scenario. This is feasible since the system integrates the editor and the player in an all-inclusive environment. In order to preview her scenario the teacher presses the button “Run”. Then, the scenario is validated and if no errors exist, the scenario is previewed. The player is automatically launched, the conditions defined in the authoring phase are initiated, the elearning services integrated in the scenario during the authoring phase are automatically launched. A mock-up virtual classroom is created and the role of the student is automatically assigned to the teacher (so that the teacher can also view what the students will view when the scenario will be available to them).

Alternate scenario: if errors occur during the validation phase, the system provides enhanced debugging functionality to the teacher, in order to enable her to make corrective actions. The debugging functionality is highly visualized (it is not assumed that the teacher has any kind of programming knowledge).

Importance: The requirement of an all-inclusive integrated (editor, player, external repositories/services/DBs) Learning Design environment has high priority. It is a challenge to design such an environment while maintaining learnability/usability. Also, the debbuging possibilities should be greatly sophisticated and no technical knowledge should be assumed on behalf of the users/instructional designers.

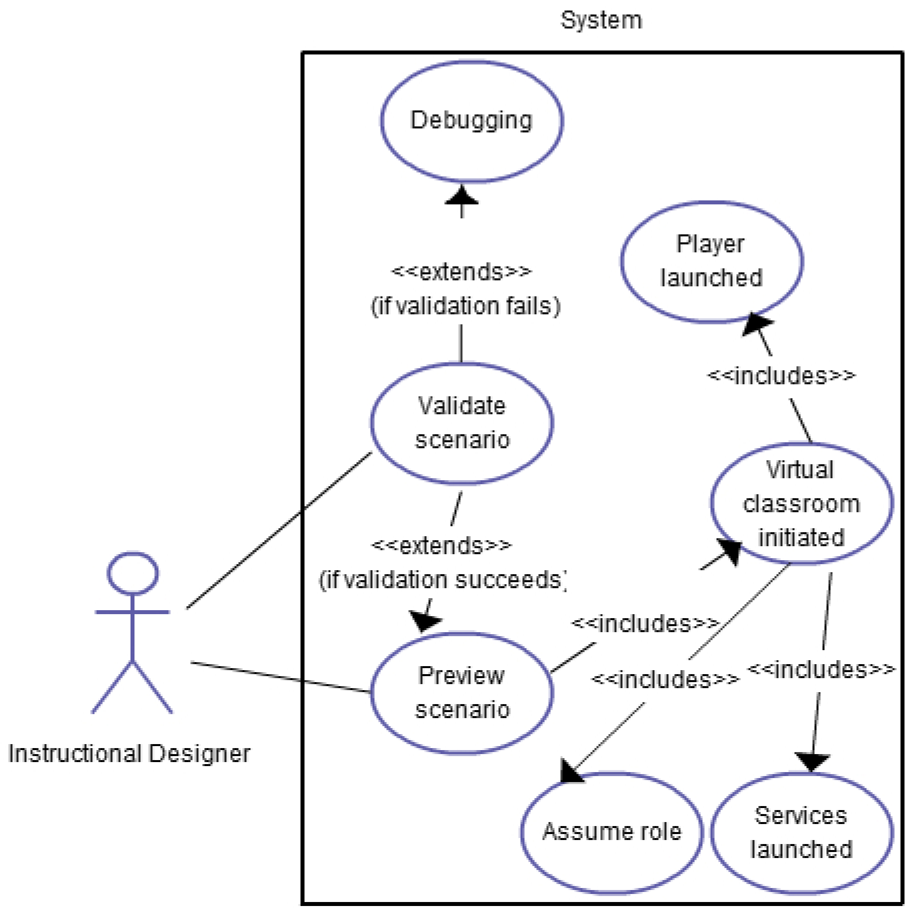



**Figure 45 Use case 5 diagram**

**Use case 6: Computer Supported Collaborative Design of a scenario/e-course**

Primary actor: Teacher(s), Instructional designer (in general)

Summary: The teacher authors a scenario collaboratively with other teachers

Main success scenario: The primary author of a scenario can invite another teacher to co-design a scenario in real-time ("What-You-See-Is-What-I-See" design principle). At the same time, they can communicate through a Voip service and discuss about the scenario.

Prerequisite requirement: use case 7

Prerequisites: Internet connection

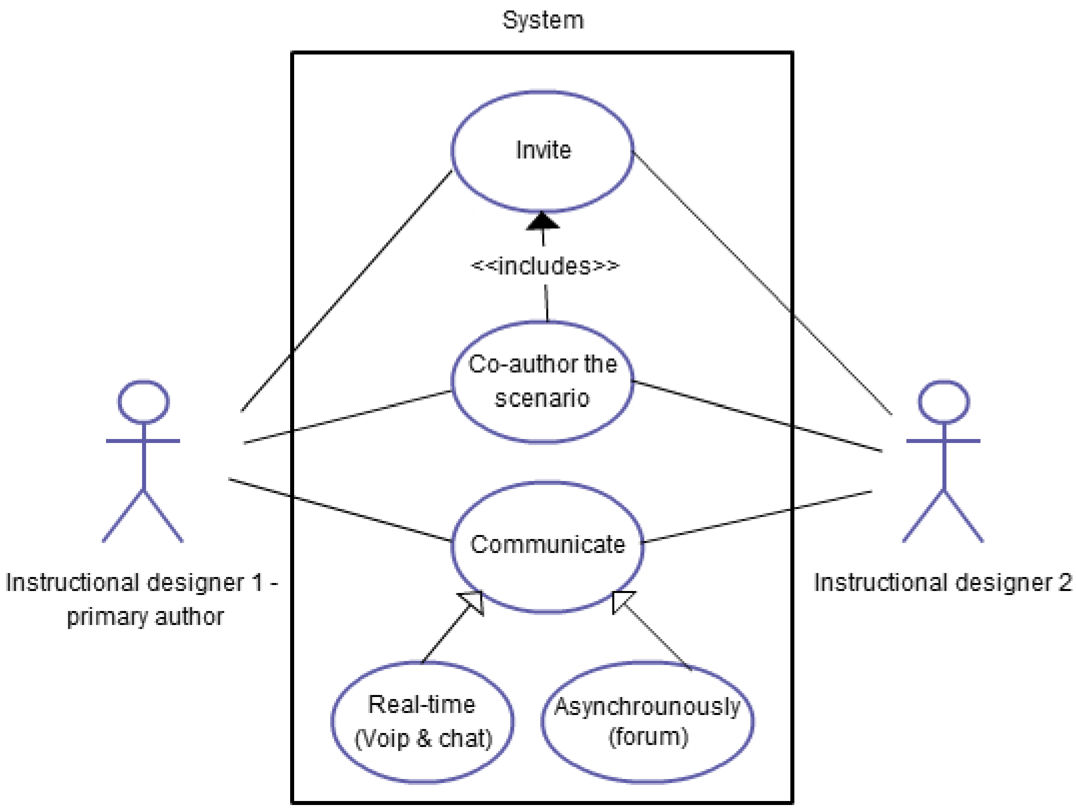



Figure 46 Use case 6 diagram

**Use case 7: Online communication**

Primary actors: All stakeholders (teachers, students, administrators, others)

Summary: Asynchronous and synchronous communication is enabled constantly through the use of Web 2.0 tool and email between all the possible stakeholders.

Main success scenario: Forum, chat and email functionalities facilitate the discussion and exchange of ideas and experiences among groups of users. Also, social bookmarking and peer-review functionalities are enabled with regards to the scenarios available through the system.

Prerequisites: Internet connection

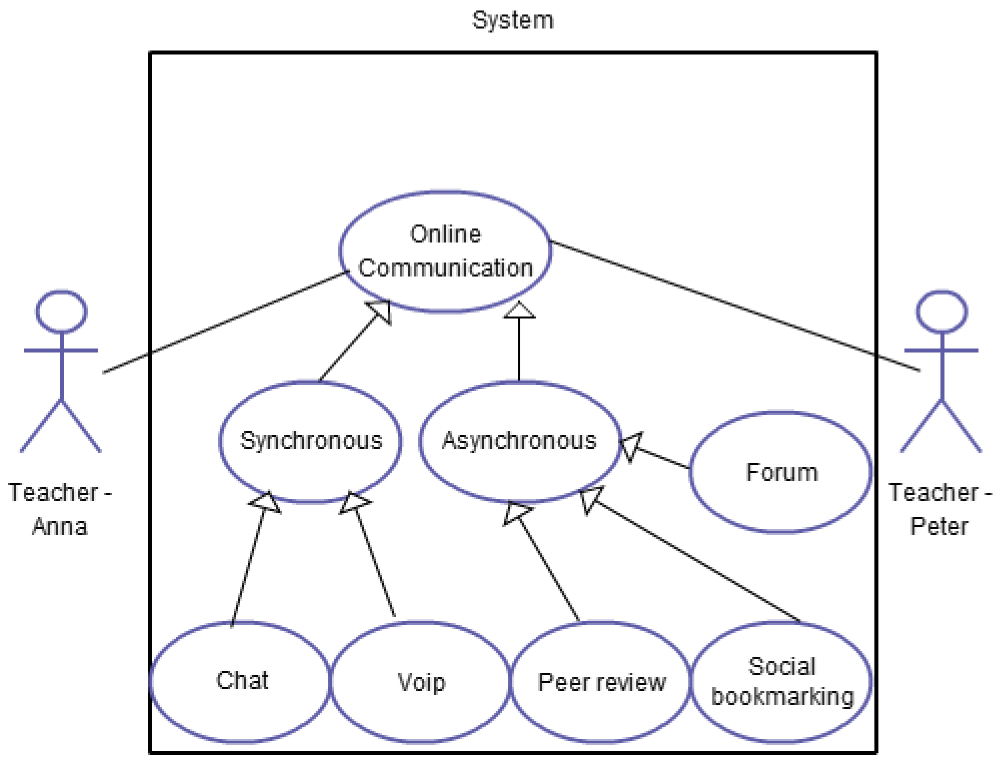



**Figure 47 Use case 7 diagram**

**Use case 8: Get help**

Primary actors: All stakeholders (teachers, students, administrators, others)

Summary: The user needs help regarding the system functionality

Main success scenario: The user can select to receive help among the following options: a) Demos, b) User forum, c) weblinks with informative material, d) Tutorials/FAQs. Also, the system can provide examples of worked-out scenarios. Due to the personalisation sub-system, the examples are differentiated with respect to the teacher profile (domain of expertise, novice/ intermediate/ experienced user etc).

Prerequisites: Internet connection

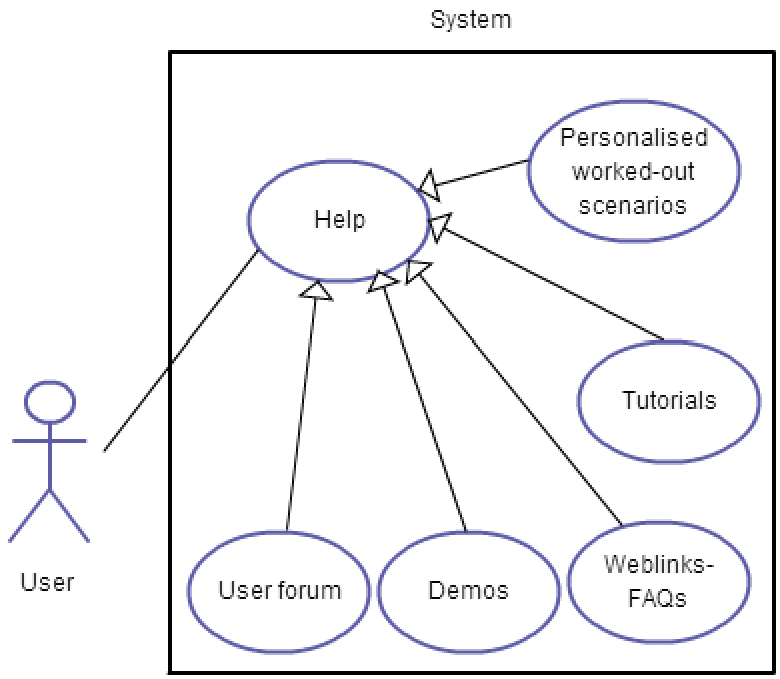



Figure 48 Use case 8 diagram

**Use case 9: Monitor the users**

Primary actors: Administrator, teacher

Summary: User tracking activity and monitoring

Main success scenario: The administrator can track the activity of all groups of users though querying the log reports. The teacher can use the learning analytics dashboard to receive visualized reports about the students progress and performance. The system is integrated with the students' DB and/or with the students eportfolio system and they inform each other. With regards to the teachers, the system is intelligent in the sense that it can gradually build the teacher profile and consequently, provide to her a personalized UI. For example, to provide more sophisticated or complex types of functionality to the more experienced or tech-savvy teachers.

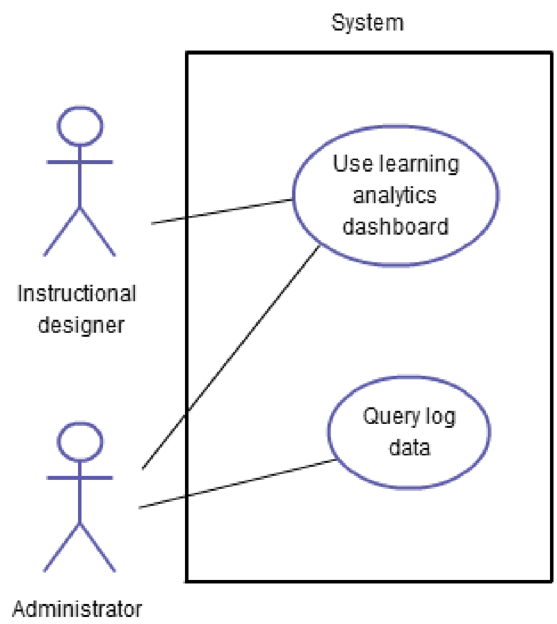



Figure 49 Use case 9 diagram

**Use case 10: Revisit your work**

Primary actor: Teacher

Summary: The teacher revisits her scenario and reconfigures its design elements

Main success scenario: The teacher reflects upon her completed scenario and, based on her needs, she can add, remove, edit or re-arrange any of the structural elements of the scenario (e.g phases, content, activities, roles etc).

Non-functional requirement: This is feasible through simple drag' n drop or point' n click actions and visualised Learning Design, as mentioned in use case 4.

Prerequisite use case: use case 4

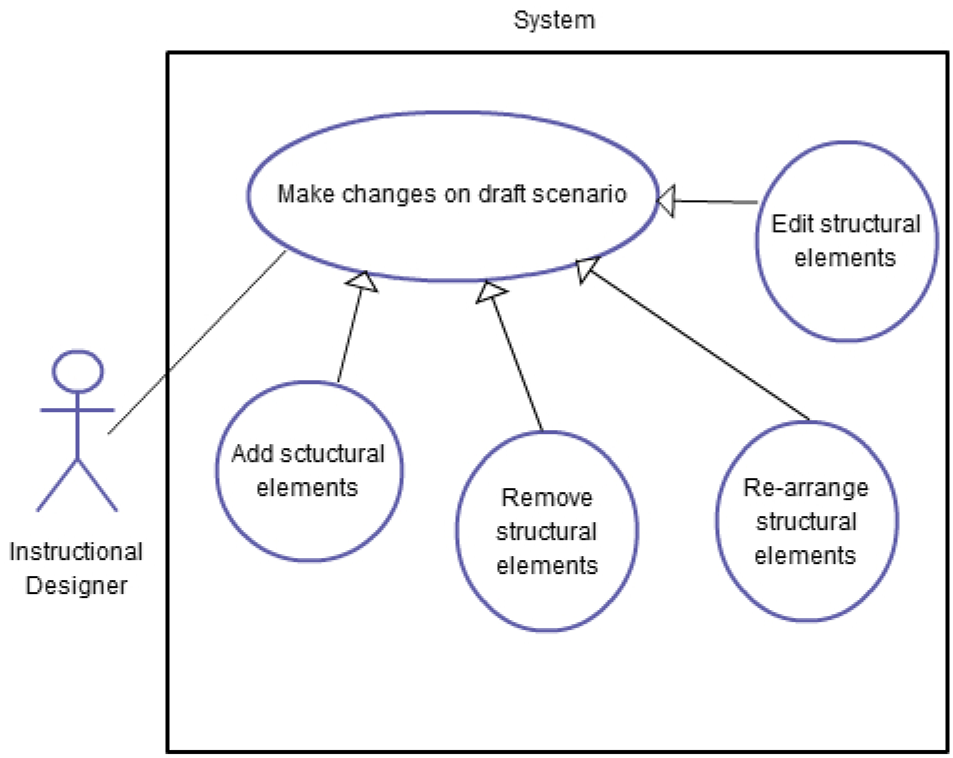



**Figure 50 Use case 10 diagram**

**Use case 11: Expose your work**

Primary actor: Teacher

Summary: The teacher exports or shares her scenario

Main success scenario: The teacher can select how to export her scenario (including the built-in elearning services and the learning content) by choosing among the following options: a) course packaging (following elearning standards), b) export as html or XML, c) export as executable file, d) upload on the player (in order to share it with their students and initiate the virtual classroom), or e) share it with their colleagues (so that it can receive ratings and comments).

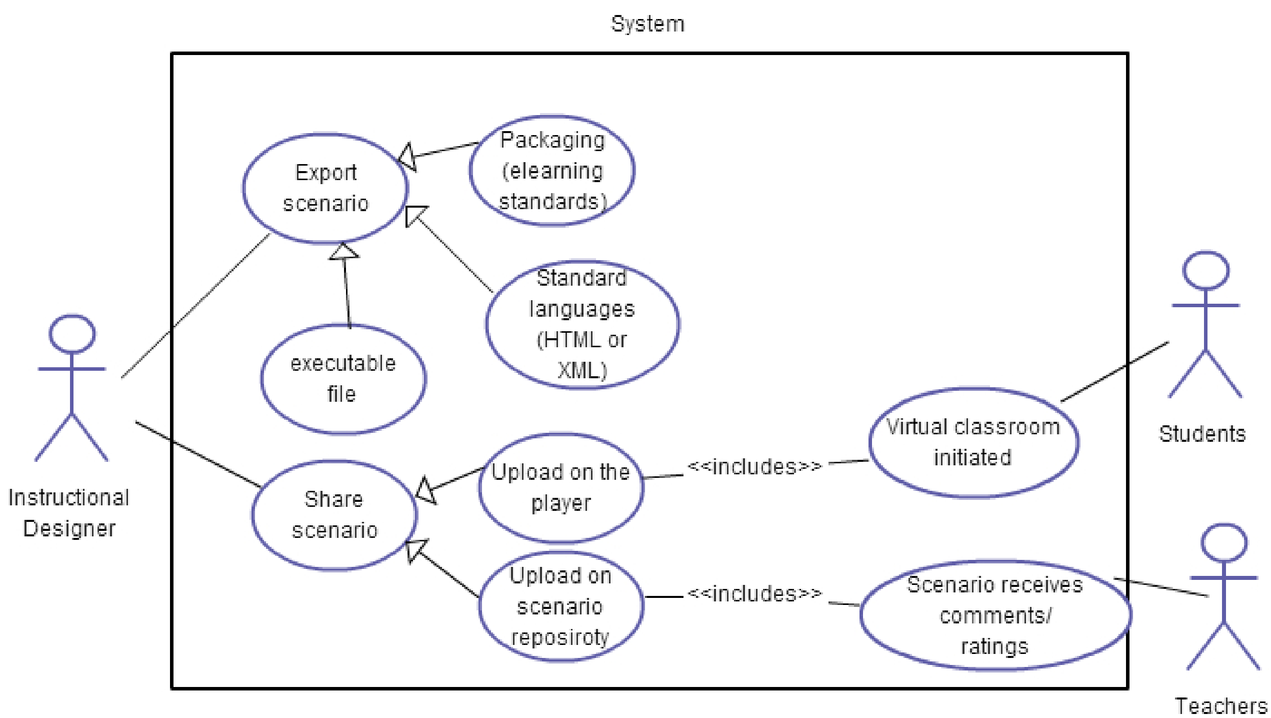


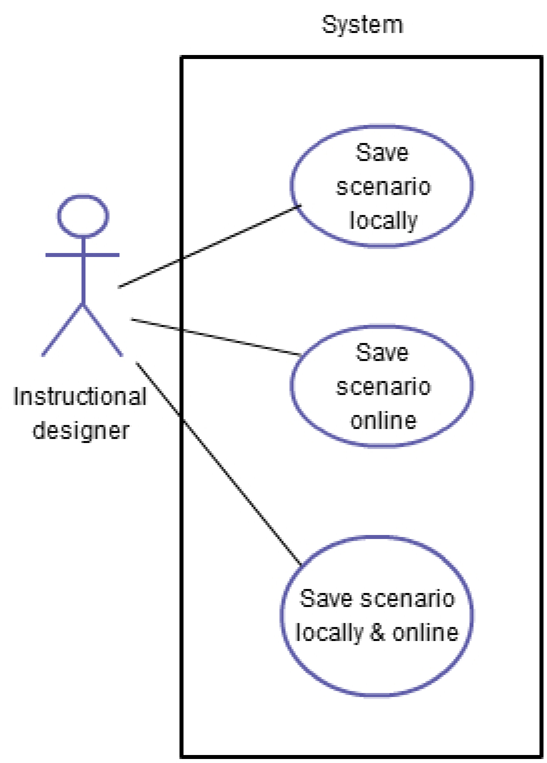

Figure 51 Use case 11 diagram

**Use case 12: Save your work**

Primary actor: Teacher

Summary: The teacher saves her design scenario

Main success scenario: The teacher has the following options: a) save her scenario locally in her computer, b) save her scenario using the online version of the system through a dedicated web-based app or online sub-system or c)save both locally & online. In parallel, the system autosaves




the draft scenario, so that it can be recovered in case the system collapses.

Figure 52 Use case 12 diagram

**Use case 13: Semantic search**

Primary actor: Teacher

Summary: The teacher uses the built-in search functionality

Main success scenario: The teacher during the authoring process might wish to search for existing content, elearning services and scenarios/courses (with their accompanying elearning services and content). For this purpose, she writes keywords using the built-in search engine, specifying whether she is seeking for content, services or scenarios. Semantic search functionality is enabled which makes the searching more intelligent and closer to the needs at stake

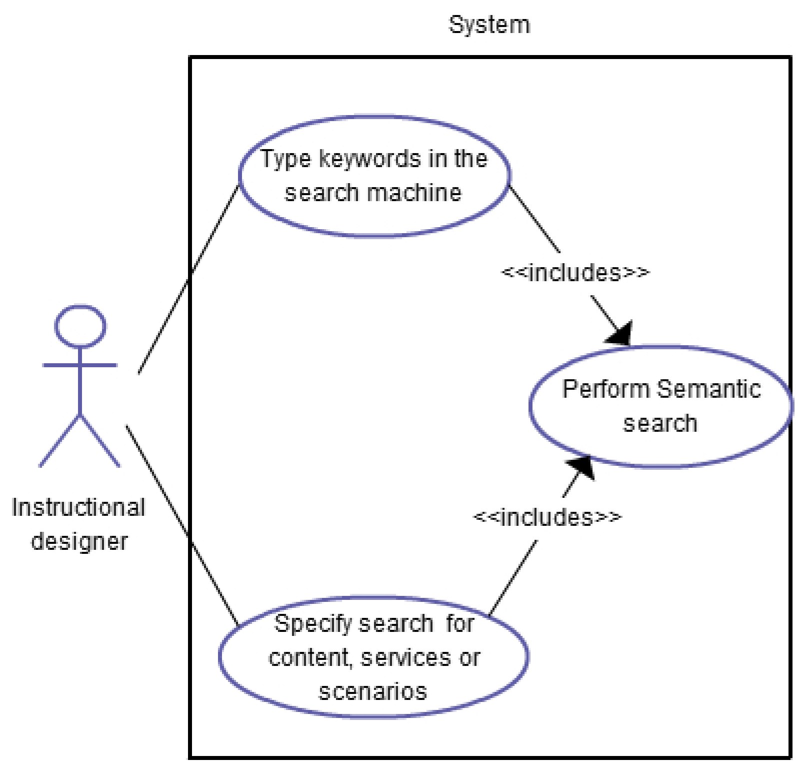



Figure 53 Use case 13 diagram

# Chapter 8. Conclusions and future research

## 8. 1. Summary of findings

The statement of the thesis is that the role of "teachers as designers" for adaptive elearning can be twofold, since their "wisdom of practice" can effectively help in overcoming the inherent difficulties of the subject matter using the affordances of adaptive e-learning and, also, they can serve as co-designers of a user-friendly adaptive learning environment.

The preliminary work which is described in Chapter 4 included several surveys in order to conclude: 1) that teachers adapt their lesson and identify important to them adaptation parameters, 2) on the specific learning style taxonomy for which teachers feel that it is relevant to their everyday practices, i.e. the VARK taxonomy, 3) on the need to design a "teacher-friendly" digital environment for adaptive e-learning (IMS-LD compliant), 4) on the need to integrate Computer Supported Collaborative Design functionality in the design of that environment

The main research questions are investigated in chapters 5 to 7. More specifically, in Chapter 5, the main question discussed is how can we feed the teacher's PCK and her personal student understanding to a technology-enhanced course that would be capable of distinguishing specific student learning characteristics and provide personalized learning paths?

The contribution of this chapter lie in the identification of a methodology for adaptive learning that embraces the "teachers as designers" concept and, at the same time, it is grounded in sound theoretical frameworks. In particular, it is based on a domain-specific learning design theory in mathematics (Simon's mathematical teaching cycle) and a generic model derived from curriculum studies (Shulman's model). It provides design pathways that integrate the phases of these theoretical frameworks to the steps of the Design-Based Research process in order to guide a design of adaptive e-learning courses so that it can be driven by the teacher's wisdom of practice with respect to the inherent difficulties of the topic. This methodology was shaped in the context of a pilot study in which I was the primary designer and the developer of an adaptive e-learning course in mathematics. This pilot study took place in two consecutive cycles of design where the participant teacher was the co-designer. The Hypothetical Learning Path, a concept introduced in the Simon's Mathematics Teaching Cycle, was exploited through the lens of adaptive eLearning which provided the opportunity to create numerous alternative paths for the diverse characteristics of the students. The creation of an adaptive eLearning strategy that integrated the wisdom of the teacher coupled with the affordances of adaptive eLearning, enabled each student to traverse his own path based on his learning style mode and his performance.

Chapter 6 reports on the empirical findings of five interventions that investigated how the exploitation of the specific learning strategy which was shaped in Chapter 5 can assist students to overcome the inherent difficulties of the content to be taught, such as topics that teachers find difficult to teach or students find difficult to understand or have misconceptions about them. Misconceptions abound in all fields, especially in science and engineering disciplines (Kalman, 2008; Bull & Gardner, 2010). Parameters of students' profile were associated with students' performance gains derived from the adaptive learning interventions. More specifically, students' prior knowledge (defined as pretest score), students' age and students' motivation on the domain are associated with the students' gain scores. Prior to that, adaptive e-courses were designed collaboratively with the participant teachers. The aim of this chapter was not just to test the effectiveness of adapting the interface to meet the needs of learners with different abilities and characteristics, but to test the proposed strategy as a whole. Adaptivity was considered an integral part of the design that enabled the creation of hypothetical learning paths which was driven by the teacher's practical wisdom.

The findings indicated that the students that followed the adaptive e-courses performed significantly better compared to those students that followed non-adaptive e-courses. In the question "Were the adaptive learning e-courses more beneficial for low-motivated learners?", the answer is negative. In addition, no significant differences on the gain scores between the different student age groups were recorded.  On the contrary, in the question "were the adaptive learning interventions more beneficial for students with low pretests scores?", the answer is positive.

In Chapter 7, I examined the questions: a) how can we design a learning environment for adaptive learning in a user-centered way?, b) how can we prioritise the design requirements of a digital environment in a user-centered way? The work described in chapters 4 and 6 provided conjectures to the work described in Chapter 7. These conjectures were a source of knowledge among the various sources of knowledge with respect to question (a). Examples of conjectures are the following:

- the outcomes of the domain theory confirm that adaptation using two methods is more efficient than using one method. This was mirrored in the designed learning environment as the support to author “rich” adaptive learning designs (i.e more than one method could be integrated in the design in a user-friendly way and they could be combined).
- the outcomes of the interventions confirm that the VARK typology is preferable among other learning styles typologies. Consequently, the designed environment incorporates this specific typology in order to author an adaptive e-course that exploits learning style, as an adaptation parameter.

The contribution of Chapter 7 is twofold: a) it exposes the design of an environment which addresses the related challenges mentioned by the participants and the literature and b) it introduces a user-centered methodology of prioritizing requirements for meeting the end users’ expectations.

The main findings from this chapter include a scenario-based RE approach which was participatory and iterative since it contained three cycles of requirements specification and validation. In eleven important parameters for the design of an adaptive learning the resulting set of UI mockups (along with accompanying descriptive texts) scored very satisfactorily during the final evaluation. Also, the ensuing design met at a great extent the expectations of the participants. With respect to question (b), the research employed the Qualitative Comparative Analysis, as a method to prioritise requirements for meeting the end users’ expectations.

In summary, the contribution of the study involves three main pillars:

- Adaptation strategy to create powerful learning designs (inherent difficulties, students with low prior knowledge levels)
- No need to repurpose, since the inherent difficulties of the subject matter apply universally. (Even when a course is adaptive, there might be still a need to repurpose it taking into account national standards or national curricula.)

- Principled methodology of end-user involvement in the design of adaptive e-courses and UIs for adaptive eLearning

## 8.2 Implications and lessons learnt

Buckhardt (2006) in his paper "From design research to large-scale impact: engineering research in education" discusses the need of approaches that develop robust solutions to recognised practical problems. Robust solutions include products or processes that have been tested empirically, both formatively in the development process and in the final evaluation. He discusses the problem that "most design research stresses the new insights it provides rather than the products and processes it has developed, valuable though these could be if developed further". He believes that the priorities of society are mainly practical, so educational research must deliver impact in practical terms but there are low levels of support for that kind of research which he calls "engineering research" (Burkhardt, 2006). Engineering research exploits research insights in order to create better tool and/or processes aiming at improved practice (ibid). This research approach is close to the philosophy that traverses this study, since it is based on a set of key elements which were also present throughout this study (Burkhardt, 2006):

- research input from earlier research and development worldwide
- design skill, led by designers who have produced exceptional materials
- co-development with members of the target communities
- feedback from successive rounds of developmental trials
- a well-defined locus of 'design control', so that wide consultation can be combined with design coherence.

Lessons learnt from the classroom interventions include the following de-contextualised guidelines for the design of adaptive e-courses:

- Focus on the inherent difficulties of the subject matter
- Use the theoretical frameworks exploited in this study to guide the discussion and the collaboration with the teachers

More specifically, concerning the collaboration process with the teacher:

- Step 1- Discuss with the teacher about topic, concepts, purpose/difficulties/objectives, prior knowledge
- Step 2- The teacher provides or suggests resources (based on the proposed conceptual mappings-chapter 4)
- Step 3- Help the teacher create the design diagram of the adaptive e-course (using a simplified version of UML)
- Step 4- Additional resources at the end of the course to avoid classroom management problems are important (see the next paragraph).

In addition to those mentioned above concerning the contribution of chapter 7, the design of the proposed digital environment is influenced by the two theoretical frameworks exploited in this study: Shulman's model of pedagogical reasoning and action and Simon's mathematics teaching cycle. The interactions sequence depicted in the UI mockups which correspond to the scenario creation (see figures 33-36) attemps to mimic the four steps mentioned above.

By making personalized learning scalable, adaptive learning has the potential to (Oxman and Wong, 2014): a) reduce course drop-out rates, b) be more effective at achieving outcomes, c) be more efficient for students, helping them achieve outcomes faster and d) free up faculty to focus on direct assistance where it is needed most. The implications also include the new role of the teachers as well as their training in order to enable them to design and run adaptive e-learning courses in their classrooms. In a survey conducted in 2013 by the Center of digital education asking the question "What aspect of education will be most impacted by a personalised learning model?", the majority of the respondents answered "the role of the teacher" (31%). Teachers can then be evaluated on their performance based on learning analytics about the learning of their students (Oxman and Wong, 2014), something that, to my view, is quite controversial since correlation does not imply causality (Scandura et al., 2013) and we should be careful on how these learning analytics are interpreted. During my study on the history of adaptive eLearning (i.e. the work that corresponds to Chapter 2) I realised that sometimes the attempts to individualise instruction were not supported by the teachers because they felt that their role could be threatened.

Finally, the work described in Chapter 7 could be used as the basis of the development of a user-friendly, standards-compliant environment for adaptive elearning to anyone interested (company or university). That, in turn, could foster engagement with and access to adaptive learning e-courses on behalf of the stakeholders that do not have good technical knowledge (instructional designers, teachers).

### 8.3 Limitations and lessons learnt

The aim of this section is the opposite of the aim in the previous sections. In retrospect, a researcher needs to amputate the things that didn't work efficiently (this section) in her research endeavor, while figuring out ways to scaling up things that did work efficiently (previous sections).

Concerning "lessons learnt" of the adaptive learning interventions described in Chapter 6, the fact that students followed different learning paths created classroom management problems. This was due to the fact that students answering correctly in the problems of the e-courses received shorter learning paths compared to their classmates that didn't answer correctly. Also, the learning pace is varying from student to student. This led to a situation in which some students had completed their lesson while others didn't. To compensate for this issue, extra learning activities should have been included after the end of the post-tests for those students that completed their lesson early.

Another issue relates to the locus of control between the system and the students. The courses designed in Chapter 6 were adaptive but not adaptable, that is, the student did not have any control over his learning path, except for the fact that since they were no synchronization points in the adaptive e-course, each student could discern his learning path in his own pace. As mentioned in (Vandewaetere et al.,2011, p. 128), the "adaptability of a system, operationalized as the degree and type of learner control that is offered based on the learner model, could serve as an additional target of adaptive instruction".

Concerning the work described in Chapter 7, limitations pertain to the software tool that was used for the creation of UI mockups (namely, "creately") which did not allowed much interactivity with the participants. That is, the participants of the requirements validation process did not receive an interactive software simulation upon which to gauge the effectiveness of the proposed design, but a set of static UI webpages. Yet, the tool was suitable for Computer Supported Collaborative Design so at the beginning of the second requirements specification cycle I distributed to each of the participants a unique URL for the UI mockups, in order to edit them as they wished. Also, google docs were used for collaboratively commenting on the UI mockups and the accompanying descriptive texts.

With respect to the answers of the participants in the evaluation questionnaire (Chapter 7), a negative outlier existed for the majority of them. For example, in questions where the majority of the participants would assign a grade of four this specific participant would assign a grade of three or even a grade of two. The specific participant has a background in graphics and mentioned that the proposed design needs to be enhanced in terms of User Experience (UX).

In this thesis, except for being the researcher I was also the designer and the developer of the adaptive e-courses and the User Interface mockups. The fact that I had to undertake three different roles entails the risk of incorporating bias in the research endeavor. Acting proactively to eliminate this risk, my research was highly participatory: during the effort described in this thesis, 75 adults and 165 children participated in different phases of the research. The adults, educators in their majority live in different cities which are located in Greece or in Cyprus.

### 8.4 Recommendations for future research

A standards-based approach towards scaling-up the development of adaptive learning is a good idea due to the utilities that such an approach may bring along, particularly reusability and sharing. Future plans involve the integration of four specific SCORM (v1.2) metadata elements that may be also used for adaptive learning:

“cmi.student_preference.audio”, “cmi.student_preference.text”, “cmi.student_preference.speed”, “cmi.core.session_time” and “cmi.student_preference.language”.

The mechanism for combining SCORM with IMS-LD is already in place, as described in (Tattersall, Burgos, Vogten, Martens & Koper, 2006).

With regards to the work described in Chapter 6, future research recommendations involve studying possible interdependencies between the adaptation parameters. In particular, the inherent learning difficulties and learning style, since they are both related to content transformations. As mentioned in (Popescu, 2010) ideally, a learning style-based adaptive educational systems should not only take into account multiple adaptation parameters as possible, but also consider possible interdependences between them. Future research plans may also include the expansion and the generalisation of the methodology by testing it with subject matters from other disciplines than mathematics and computer science.

We have seen in Chapter 6 that using two adaptation methods was better than using one. An important and yet unanswered question regarding adaptive learning systems is how much adaptivity is enough, or optimal? (Oxman  & Wong, 2014). I believe that, provided that we should scale up adaptive eLearning and widening teachers' participation throughout the lifecycle of an adaptive e-course, this question should be answered while having in mind the balance between the learning effectiveness of the adaptive e-course on the one hand with the complexity of the adaptive eLearning strategy and the ensuing implementation difficulty of the adaptive e-courses on the other.

Concerning the balance between system adaptability and adaptivity, Vandewaetere et al  (2011) explicitly mention that "no studies have been focusing on learner control as instructional technique in adaptive learning environments. The degree and type of learner control that is offered to learners could be adjusted to their needs, abilities and goals" (p. 128). Consequently, another possible line of research is focusing on how to partially assign the control of the learning path to the students in a way that maximises the learning outcomes, while investigating how a standards-based adaptive learning environment could support that effectively and efficiently.

Furthermore, the design described in Chapter 7, could be further enhanced taking into account what was mentioned in the previous section as well as the participants' opinions since the majority of the participants expressed their views on the design through an open ended question ("would you like to add anything else concerning the proposed design solution?") at the end of the evaluation questionnaire. I would be interested in enhancing the design in terms of User

Experience.

Another area for future research that touches upon the pedagogical aspect of this research is related to the investigation of the association of the kinesthetic and the multimodal type of learner with mobile learning probably in tandem with context awareness. I proposed an extension of the LD Information model for the case of mobile and contextual learning.

The proposed extension of the Learning Design information model is shown in the UML diagram in figure 54 below. The non-colored part of the UML diagram comprises the IMS LD information model which specifies learning activities performed within an environment that contains learning objects and services. The colored parts of the diagram constitute the generalization of the conceptual design of this model, in order to include mobile and contextual learning.

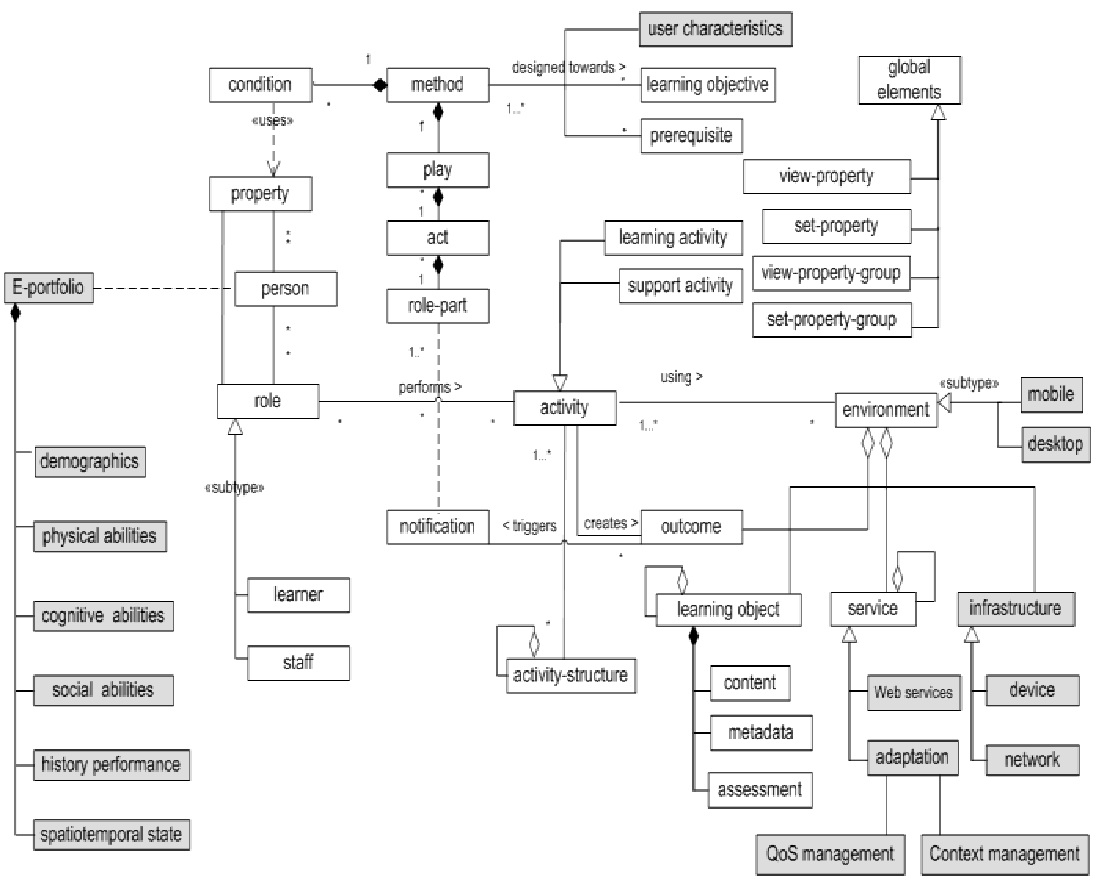



**Figure 54 Extended IMS-LD Information Model**

Ideologically speaking, I believe that this thesis contributes to the Opening-Up Education movement. This movement is related to a wide range of issues, but in the context of this thesis, I have worked towards the exploitation of open eLearning standards and the widening of participation and access to innovative pedagogies in order to cultivate the 21st century skills. I believe that teachers are the primary change agents of any educational system.

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