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Julien Broisin

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Mémoire

En vue de l'obtention de l'

HABILITATION À DIRIGER DES RECHERCHES

Délivrée par l'Université Toulouse III – Paul Sabatier
Discipline Informatique

Présentée par Julien Broisin
le 16 décembre 2020

**Towards intelligent technology-enhanced learning solutions
for transforming higher education:
contributions and future directions**

JURY

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Vanda Luengo	Professeure, Sorbonne Université	Rapporteuse
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Philippe Vidal	Professeur, Université Toulouse III - Paul Sabatier	Garant

Résumé

Ce manuscrit présente nos principales contributions pour améliorer les pratiques éducatives dans l'enseignement supérieur à l'aide des nouvelles technologies. Nous avons abordé trois grands défis. Premièrement, nous avons proposé un cycle de vie des ressources éducatives libres facilitant leur production et leur gestion dans des environnements complexes, ainsi qu'un ensemble d'outils et de processus soutenant les acteurs de l'éducation dans ces tâches. Nous avons également proposé un modèle et des outils fondés sur une approche par compétences pour faciliter l'alignement des formations avec les compétences du monde socio-économique, ainsi que l'orientation professionnelle des apprenants. Dans un deuxième temps, nous avons étudié comment assurer la qualité de la surveillance des activités des utilisateurs au sein des environnements de formation en vue de personnaliser leur apprentissage. Nous avons conçu un modèle flexible pour décrire les expériences d'apprentissage des utilisateurs, ainsi qu'une architecture respectueuse de leur vie privée pour collecter et stocker les données de ces expériences. Pour garantir la qualité du processus de collecte, nous avons proposé une méthodologie indépendante des plates-formes guidant les techniciens dans la conception de processus de surveillance auto-adaptatifs en fonction de leurs exigences. Enfin, nous avons conçu deux systèmes interactifs pour favoriser l'apprentissage actif à grande échelle. Le premier met en œuvre un processus visant à améliorer l'instruction par les pairs et l'engagement des apprenants dans des activités d'évaluation formative. Le second soutient l'apprentissage exploratoire et favorise les interactions sociales et les activités collectives des apprenants dans des laboratoires distants.

À partir de ces contributions développées dans le cadre de projets nationaux et internationaux, un plan de recherche est également présenté. Il s'articule autour de deux axes principaux : (1) la conception de systèmes intelligents pour soutenir les acteurs de l'éducation dans des contextes d'apprentissage massifs, et (2) l'étude des systèmes de recommandation fondés sur les compétences. L'objectif principal du premier axe est d'explorer l'apprentissage de l'informatique, et les activités d'évaluation formative. Les principales contributions attendues dans le domaine de l'apprentissage de l'informatique sont doubles. Premièrement, je prévois de fournir des lignes directrices et des méthodes aux praticiens et aux chercheurs pour comprendre le comportement des apprenants lorsqu'ils programment, et détecter les stratégies d'apprentissage (in)efficaces. Deuxièmement, ces analyses serviront de fondement à l'élaboration de la prochaine génération d'outils destinés à soutenir la programmation et l'autorégulation de l'apprentissage. En ce qui concerne l'évaluation formative, je vais étudier comment améliorer le feedback fourni aux enseignants et aux apprenants et accroître la qualité des activités d'évaluation formative en utilisant l'extraction automatique d'arguments écrits et les visualisations interactives. Le deuxième axe de recherche consistera à étudier comment les techniques d'apprentissage symbolique et automatique peuvent être combinées pour améliorer les systèmes de recommandation exploitant des relations sémantiques riches entre compétences. D'une part, je proposerai des méthodes et des systèmes permettant aux chercheurs de mieux comprendre les stratégies d'apprentissage mises en œuvre par les apprenants. D'autre part, les résultats de cette recherche feront avancer les travaux actuels sur l'intelligence artificielle explicable dans l'éducation en général, et dans les approches par compétences en particulier.

Abstract

This manuscript presents our main contributions on how technology can be used to improve educational practices in higher education. We have addressed three main challenges. First, we proposed a lifecycle for open educational resources that facilitates their production and management in complex environments, as well as a set of tools and processes supporting educational stakeholders in these tasks. We also proposed a competence-based model and tools to facilitate alignment of training programmes with competences of the socio-economic world, as well as professional orientation of learners. Second, we studied how to ensure quality-oriented monitoring of users activities within learning environments and beyond. We designed a flexible model to describe user learning experiences, and a privacy-aware architecture to collect and store the data of these experiences. To ensure quality of the data collection process, we proposed a platform-independent methodology for guiding technicians in designing self-adaptive monitoring processes according to their requirements. And third, we investigated how to design interactive learning systems to foster active learning at scale. We contributed with two tools. The first one implements a process to enhance peer instruction and learners' engagement in formative assessment activities. The second supports inquiry-based learning and promotes learners' social interaction and group activities in remote laboratories.

On the basis of these contributions developed in national and international projects, a research plan is also presented. It is organised in two main axis: (1) designing intelligent systems to support stakeholders in large scale learning settings, and (2) studying competence-based recommender systems for personalised learning. The main objective behind the first line of research is to explore learning at scale in computer education, and formative assessment activities. The main expected contributions to the field of computer education are twofold. First, I plan to provide guidelines and methods for practitioners and researchers for analysing learners' programming behaviour and detecting effective and ineffective learning strategies. Second, these analysis will be the basis for developing the next generation of tools to support learning programming and self-regulation. With regards to formative assessment, I will explore how to enhance feedback delivered to both teachers and learners and increase quality of formative assessment activities using argument mining and interactive visualisations. The second line of research will investigate how symbolic and machine learning techniques can be combined to support semantic- and competence-based recommender systems. On the one hand, I expect to contribute with methods and systems for researchers to help better understand learners' strategies in a competence-based environment. On the other hand, the results of this research will advance current works on explainable artificial intelligence for education, and in competence-based approaches in particular.

Acknowledgements

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Part I

Curriculum Vitae

Julien Broisin

Born September 13th, 1978, La Celle Saint Cloud, France, French nationality

Marital status Single

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Academic Degrees

2007 **Qualification** to apply to associate professor positions.
Section 27: Computer Science.
Reference number: 07227176987.

2006 **PhD in Computer Science**, highest honors.
University of Toulouse III, France.
IRIT Lab. – SIERA team.
Title: *Un Environnement Informatique pour l'Apprentissage Humain au Service de la Virtualisation et de la Gestion des Objets Pédagogiques.*

2003 **Research Master (DEA in France)** in Networks and Telecommunications.
University of Toulouse III, France.
IRIT Lab. – SIERA team.
Title: *Fédération de Systèmes de Gestion pour une Gestion Proactive de la Qualité de Service Applicative.*

Professional Experience

2007 - present **Associate professor** (*Maître de Conférences* in France) in Computer Science.
University of Toulouse, Institute of Technology.
IRIT Lab., France.

2006 - 2007 **Teaching and research assistant** (*ATER* in France) in Computer Science.
University of Toulouse, Institute of Technology.
IRIT Lab., France.

2003 - 2006 **PhD student** in Computer Science.
IRIT Lab., France.
Teaching assistant (*Moniteur* in France) in Computer Science.
University of Toulouse, Department of Mathematics, Computer Science and
Management.

Research Activities

My research investigates how technology can be used to improve educational practices in higher education. It is organised around three main challenges: (1) Development of open educational resources and competence-based curriculum; (2) Quality-oriented monitoring of user learning experience; and (3) Design of interactive learning systems to foster active learning. Providing higher education institutions with the technological scaffold they need to better support the learning and teaching tasks represents the main direction of my research programme. I will specifically investigate the two following lines of research: (1) intelligent systems to support stakeholders in massive learning settings, and (2) meaningful competence-based personalised learning.

List of publications

Here is the list of my publications. When available/applicable, the acceptance rate (AR) and/or the rank (R) of the publication according to the ATIEF ranking (see <http://atief.fr/ressources/classement>) are given.

Type of publication	Numb.
Edited books	5
International journals with editorial board and specialist reviewers	10
National journals with editorial board and specialist reviewers	7
Book chapters in printed books	1
International conferences with proceedings and program committee	49
National conferences with proceedings and program committee	19
Conference papers without published proceedings	3
Reports	4
Ph.D thesis	1
Master thesis	1
Other publications	1
Total	101

Edited books

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International journal papers

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- [96] Broisin, J., Butoianu, V., Catteau, O., Dupeyrat, C., Escribe, C., Huet, N., Maillard, A., Marquié, D., Motak, L., Roussel, B., Sakdavong, J.-C., Sapta, C., Teyssié, C., and Vidal, P. (2013). *Rapport d'avancement de contrat ANR à T0+30 - Programme CONTINT 2010 - Projet COMPETENCES ANR-10-CORD-011-01*. Toulouse.
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- [98] Broisin, J., Vidal, P., Chevalier, Y., and Balbiani, P. (2006). *Middleware et Services : Internet Services Integration*. Toulouse.

Ph.D theses

- [99] Broisin, J. (2006). *Un Environnement Informatique pour l'Apprentissage Humain au service de la Virtualisation et de la Gestion des Objets Pédagogiques* (Doctoral thesis, Université Paul Sabatier, Toulouse, France). Retrieved from <https://tel.archives-ouvertes.fr/tel-00367682/>

Master theses

- [100] Broisin, J. (2003). *Fédération de Systèmes de Gestion pour une Gestion Proactive de la Qualité de Service Applicative* (Master's thesis, Université Paul Sabatier, Toulouse, France).

Other publications

- [101] Catteau, O., Vidal, P., and Broisin, J. (2006). Commentaires apportés à l'enquête pro-

batoire de l'AFNOR concernant l'avant-projet de norme Pr NF Z76-040 traitant le profil français d'application du LOM (LOM-FR) - Métadonnées pour l'enseignement.

Research awards

- 2017** **Best paper award [74].**
8^{ème} Conférence sur les Environnements Informatiques pour l'Apprentissage Humain (EIAH), Strasbourg, France.
- 2016** **Best paper award [32].**
16th IEEE International Conference on Advanced Learning Technologies (ICALT), Austin, United States of America.
- 2016** **Best paper award** (*only the name of the Ph.D. student, R. Venant, appears on the paper*).
6^{ème} Rencontres Jeunes Chercheurs en EIAH (RJC-EIAH), Montpellier, France.
- 2014** **Best paper award [77].**
Technologies de l'Information et de la Communication pour l'Enseignement (TICE), Béziers, France.
- 2011** **Best paper award [50].**
International Conference on Mobile, Hybrid, and On-line Learning (eL&mL), Gosier, Guadeloupe.

Invited lectures at international conferences

- 2016** **Lab4CE: towards open computer science education.**
Open Harvest Workshop, Chania, 05/20.
- 2015** **E-learning research at IRIT.**
10th International Conference on Computer Science and Information Technologies, Yerevan, 09/28-10/02.
- 2014** **Federation of Usage Datasets: an Experimentation with the Data-TEL Challenge.**
11th Educational Repositories Network Conference, Athens, 05/06.
- 2008** **Norms and Standards for Interoperability of Learning Object Repositories.**
Association for Medical Education in Europe, Prague, 08/30-09/03.

Invited lectures at national conferences

- 2020** **Approches par compétences : de la conception de cursus de formation à la génération automatique de séquences d'apprentissage personnalisées.**
Workshop IMT4ET, online, 05/27-05/28.

International and national projects

From the very beginning, my research is connected to funded projects. Being involved in such projects has provided me with a varied experience on project proposal writing and management. My involvement in international and national projects is described in the sections below.

International projects

- 2012 - 2015** **Open Discovery Space: A socially-powered and multilingual open learning infrastructure to boost the adoption of eLearning resources.**
<http://www.opendiscoveryspace.eu/>
Funding institution: European Commission.
Budget (Université Paul Sabatier only): 67.000€.
Number of partners: 50+.

Description: This project aimed to serve as an accelerator of the sharing, adoption, usage, and re-purposing of the existing educational content. Its objectives were threefold: (1) to involve school communities in innovative teaching and learning practices, (2) to demonstrate the potential of eLearning resources to meet the educational needs of these communities, and (3) to assess the impact and document the whole process into a roadmap including guidelines for the design and implementation of effective resource-based educational activities.

My roles and contributions: Principal investigator, Université Paul Sabatier. I was involved in work package 7 (Open Learning Content) to design and specify resource repositories and aggregation services, and to align and integrate external/new educational content collections. In work package 8 (Social Learning Data), I was in charge of designing and deploying a social data infrastructure to aggregate, store, process and expose social and usage data related to learning resources. In both work packages, I (1) participated in the writing process of deliverables; (2) managed the budget allocated to Université Paul Sabatier; (3) participated in the dedicated meetings.

- 2011 - 2014** **LATIn: A methodology for collaborative creation of open textbooks and a technological platform to support the collaborative creation, adaptation, mixing and re-use of open textbooks.**
<http://www.latinproject.org>

Funding institution: European Commission.

Budget (Université Paul Sabatier only): 63.000€.

Number of partners: 9 Latin American partners & 3 European partners.

Description: The general objectives of the project were to improve the accessibility to the Latin American University for low-income students, and to reduce the dropout rate due to financial issues. The specific objective of the project is the creation and dissemination of a Collaborative Open Textbook Initiative for Higher Education tailored specifically for Latin America.

My roles and contributions: Principal investigator, Université Paul Sabatier.

In this project I (1) brought my expertise in collaborative creation of learning content; (2) reviewed the ideas for the collaborative creation of learning materials suggested by the Latin American partners while providing strategies for their development; (3) supported the definition of a set of methodologies for the collaborative creation of open textbooks in Latin America; (4) managed the budget allocated to Université Paul Sabatier.

2003 - 2006

Network of Excellence PROLEARN.

<http://prolearn.archiv.zsi.at/>

Funding institution: European Commission.

Budget (Université Paul Sabatier only): 70.000€.

Number of partners: 19.

Description: This project dealt with technology-enhanced professional learning. Its ambition was to bring together research groups in the area of professional learning and training, thus bridging the gap between research and education at universities and training and continuous education that is provided for and within companies.

My roles and contributions: PhD student, Université Paul Sabatier.

I was involved in the work package “Learning Objects, Metadata and Standards” to (1) contribute to a set of standard specifications for learning objects integration into repositories; (2) develop a Moodle plugin based on these standards to set up interoperability between this learning management system and a set of learning object repositories; (3) dispense end-users training sessions about how to use the plugin.

National projects

2019 - 2022

COMPER: Une approche par compétences pour le diagnostic, la régulation et la personnalisation de l'apprentissage.

<https://comper.fr>

Funding institution: Agence Nationale de la Recherche.

Budget (Université Paul Sabatier only): 83.000€.

Number of partners: 5.

Description: The objective of this project is to support personalised learning through a competence-based approach. Bringing together multidisciplinary researchers, the project aims to (1) design a competence profile of learner, (2) use these profiles to personalise learning activities and paths, and (3) help learners to self-regulate learning through motivational levers. The project is based on 4 experimental fields of different levels and disciplines in order to evaluate the genericity of the developed models and tools.

My roles and contributions: Principal investigator, Université Paul Sabatier. My tasks in this project consist in (1) coordinating 3 work packages dealing respectively with the design of a meta-model of competences; the visualisations of learners' competency profiles to support both teachers to adapt their learning scenarios, and learners to self-regulate their activities; the recommendation of personalised learning paths according to learners' competence profile; (2) coordinating the writing process of the deliverables of these WPs; (3) coordinating the research activities of the Université Paul Sabatier team (including one postdoc researcher and one PhD student); (4) managing the budget; and (5) organising and participating in the project meetings.

2019 - 2022

B4MATIVE! L'Évaluation formative à l'ère du BYOD et de l'École numérique.

Not available yet

Funding institution: Direction du Numérique pour l'Éducation.

Budget (Université Paul Sabatier only): 138.000€.

Number of partners: 2.

Description: The aim of the project is to design quality-oriented formative assessments, from both the learner and teacher points of view. The project mainly focuses on the following objectives: to promote learner argumentation in order to foster her reflective process about her knowledge, her ability to put it in words and to organize it; to support each student to self-position individually and collectively, and engage learners in the self-regulation process; to support teachers to formulate quality-oriented questions from a pedagogical point of view.

My roles and contributions: Coordinator of the project.

As the coordinator of this project, I wrote the proposal and am now in charge of: (1) coordinating the research activities of the Université Paul Sabatier team (including one PhD student and one engineer); (2) managing the budget; (3) coordinating the writing process of all deliverables; (4) organising and participating in the meetings and activities related to the project; (5) training teachers to our tool in the academy of Nancy-Metz.

2014 - 2017

Orphée: Organisation de la Recherche Pluridisciplinaire en E-Education.

<http://www.orphee-edu.fr/>

Funding institution: Agence Nationale de la Recherche.

Budget (Université Paul Sabatier only): 10.000€.

Number of partners: 20+.

Description: The Orphée network involves French research teams investigating Technology-Enhanced Learning challenges and aims to: (1) build a community dedicated to e-education including private companies, professional associations, decision-makers, research laboratories and universities; (2) structure this community into a joint task force able to bring innovative solutions to TEL challenges; (3) articulate the three following facets: International, Enterprises and Training & Experimentations.

My roles and contributions: Researcher, Université Paul Sabatier.

My main tasks were related to the dissemination of the project, as I (1) chaired the organization committee of the 1st Orphée Rendez-Vous (see further); (2) co-authored one of the grand challenge related to massive learning of computational thinking; (3) participated in two *French corners* at international conferences to present the TEL research activities of my lab.

2010 - 2015

COMPETENCES: Processus global de réingénierie pour l'acquisition et le développement de compétences.

No public URL anymore

Funding institution: Agence Nationale de la Recherche.

Budget (Université Paul Sabatier only): 192.000€.

Number of partners: 4.

Description: This project investigated how competences can be acquired in a blended learning context. Its main mission was to set up a quality methodology related to a global reengineering process facilitating acquisition and development of learners' competences, and based on relevant indicators to enhance the learning environment.

My roles and contributions: Researcher, Université Paul Sabatier.

I have been deeply involved in the proposal writing process, and I was in charge of: (1) coordinating 1 work package related to the definition, collect, storage and aggregation of tracking data and indicators; (2) co-supervising the activities of the PhD student involved in this work package; (3) coordinating, for the last 16 months of the project, the research as well as the administrative activities of the whole project; (4) writing the final report.

2009 - 2012

IMAP: Information Management for Avionics Platform.

No public URL available

Funding institution: Direction Générale de l'Armement.

Budget (Université Paul Sabatier only): 123.000€.

Number of partners: 4.

Description: This project, initiated by Airbus©, aimed to study how

the information systems embedded into aircrafts could be progressively moved towards traditional IT systems, even if domain specific constraints should be kept in mind.

My roles and contributions: Researcher, Université Paul Sabatier.

In this project, my main tasks consisted in (1) contributing to 1 work package related to the monitoring activities required for self-management and self-reconfiguration of onboard systems according to a predefined quality of service; (2) co-supervising the PhD student hired for this work package; (3) contributing to the deliverables of this work package; (4) participating in the meetings and activities related to the project.

2007 - 2010

CEAGMATIC: Conception et Evaluation d'Aides au Guidage Métacognitif dans l'Apprentissage avec les Technologies de l'Information et de la Communication.

No public URL anymore

Funding institution: Agence Nationale de la Recherche.

Budget (Université Paul Sabatier only): 77.000€.

Number of partners: 3.

Description: The purpose of the project was to design and evaluate a metacognitive guidance tool enabling learners to appropriately use assistance during the learning process. The guiding tool featured two levels of guidance. The first level was learner-controlled assistance, and provided advice for using assistance if the learning system was incorrectly used. The second level was program-controlled assistance that self-adapted to the learner's behaviour.

My roles and contributions: Researcher, Université Paul Sabatier.

In this project I was responsible for: (1) the coordination of 1 work package dealing with the design, specification and development of the guidance tool according to inputs provided by experts in psychology and metacognition; (2) the co-supervision of the PhD student hired for this work package; (3) the organisation and writing of the deliverables of this work package; (4) the organisation of meetings and activities related to the project.

2006

IFAU: IP for Avionics Uses.

No public URL available

Funding institution: Direction Générale de l'Armement.

Budget (Université Paul Sabatier only): 29.000€.

Number of partners: 2.

Description: This project, initiated by Airbus©, studied communication systems capable of securely exchanging data between airplanes and grounded information systems. The objective was to provide insights about various technologies in order to inform the company about its forthcoming research and benchmarking activities.

My roles and contributions: Researcher, Université Paul Sabatier.

In this project my main tasks consisted in: (1) studying the state of the art about existing and upcoming middleware concepts and technologies, with a focus on service-oriented architectures; (2) participating in meetings and activities related to the project.

Collaboration with other groups

2006 - 2013 **Agence Française de Normalisation (AFNOR).**

The group *Métadonnées* (GE4) of the French agency for standardisation focuses on metadata to describe educational resources. Its mission is to take part in the discussions and reflections related to the national and international standards being elaborated (such as the ISO Metadata for Learning Resources or the IEEE Learning Object Metadata).

My contributions: I was a member of the GE4 group, participated in the virtual and physical meetings, and gave comments on the standards being designed. My main contribution was the introduction of an additional field within the LOM-FR standard.

2006 - present **Latin American Community of Learning Objects (LACLO).**

<http://www.laclo.org/>

LACLO is an open and international community composed of people and institutions interested in research, development and use of technologies dedicated to learning objects in the educational area in Latin America. Its main mission consists in articulating and joining the different efforts initiated in this geographical region to offer online, open and personalised curriculums of quality to anyone.

My contributions: I'm a member of this community and act as an expert to give strategic and technological advices. The main outcome of my participation in this community is a partnership with 9 Latin American partners in the context of the LATIn project funded by the European Commission (see above).

2005 - present **Association des Technologies de l'Information pour l'Éducation et la Formation (ATIEF).**

<http://atief.fr/>

This national association aims at promoting research, education, training and knowledge in the Technology-Enhanced Learning domain. It is composed of a set of national public and private institutions and contributes to their national and international visibility.

My contributions: I'm a member of the association since 2005, and elected member of the administrative board since 2017. My main contribution include: (1) organisation, with other members of the research team, of the

2013 EIAH conference (see section “Conference and workshop organization” below); (2) coordination of the work force responsible for establishing, each year, the ranking of technology-enhanced learning journals and conferences; (3) management of the web site.

2003 - 2017 **ARIADNE Foundation.**

The ARIADNE Foundation was an international not-for-profit association that from 1995 to 2017 has been advocating the share and reuse of digital resources that can be used to support learning. To support this goal, the members of the ARIADNE Foundation have been developing a standards-based technology infrastructure that allows the publication and management of digital learning resources in an open and scalable way. The vision that drove the continuous development of this infrastructure was to provide flexible, effective and efficient access to large-scale digital collections in a way that went beyond what typical search engines provided.

My contributions: I was a member of the steering committee from 2004 to 2017. I have been the web site administrator from 2003 to 2011. I also designed and implemented a component compliant with the specifications defined during my PhD thesis to capture and store usage metadata; this component has been integrated into the tool responsible for searching and indexing learning objects.

Other activities

Collective responsibilities

2018 - present Coordinator of the e-learning application area.

Institut de Recherche en Informatique de Toulouse.

<https://www.irit.fr/domaine-education/en/>

The IRIT laboratory is organised around 6 key application areas. The objective of these working groups is to federate researchers with different expertises but studying a common research question. The e-learning working group comprises around 25 researchers from 7 different IRIT teams, and investigates topics related to technology-enhanced learning.

My contributions: I am responsible for: (1) disseminating activities of the group inside the laboratory; (2) organising the monthly meeting; (3) selecting, once a year and with other group members, the set student-supervisor-subject to be submitted to the doctoral school for PhD scholarship.

2017 - present Designated member of the Administrative Board.

Structure Fédérative de Recherche, École Supérieure du Professorat et de l'Éducation (ESPÉ, Toulouse).

<http://espe.univ-toulouse.fr/accueil-/recherche/>

This research initiative, supported by the ESPÉ of Toulouse, encompasses

more than 20 research laboratories from the University of Toulouse to produce knowledge for teaching and learning through research-innovation-field actions. It is organised in three different topics: (1) teacher's task, didactic and curriculum engineering; (2) learning paths differentiation; (3) technology-enhanced learning.

My contributions: The role of the administrative board is to give its agreement about membership of laboratories, to select scientific events that will receive funds from the structure, or to prepare calls for scientific as well as experimental projects. I represent the Université Toulouse III – Paul Sabatier in this structure.

Elected member of the Administrative Board.

Association des Technologies de l'Information pour l'Éducation et la Formation (ATIEF).

<http://atief.fr/>

The role of the ATIEF administrative board is to participate in the organisation of the conferences EIAH and RJC-EIAH, and to voice its opinion on the creation of specific work groups, the engagement of the association within collective initiatives and other associations such as the Société Informatique de France, or the proposal of scientific researchers to represent the association at national and international events.

My contributions: I responsible for the working group in charge of classifying international and national scientific journals and conferences that are relevant for computer science researchers in the TEL area. With two other colleagues, I also ensure the administration and maintenance of the ATIEF web site.

2014 - present Co-coordinator of Hippocampe Trainings.

Toulouse Doctoral School of Mathematics, Computer Science And Telecommunications.

<https://www.irit.fr/Accueil,1697?lang=fr>

This initiative aims to attract secondary school students towards research in computer science. A Hippocampe training consists in receiving a secondary school classe at the university during two consecutive days, to expose them in an understandable way a concrete research question, and to make them think, elaborate and present a possible solution. A senior researcher, with the help of several PhD students, is responsible for guiding and tutoring secondary students in their reasonings and findings.

My contributions: In collaboration with another researcher, I put online some information about the big picture of these trainings and explained the principles and objectives of this initiative to the PhD students of my laboratory. Until now, I organised two trainings with the secondary school of Moissac: one in September 2016 and the other in September 2017.

2013 - present **Coordinator of the work group "Architecture and Information Systems for TEL environments".**

Structure Fédérative de Recherche, École Supérieure du Professorat et de l'Éducation (ESPÉ, Toulouse).

<http://espe.univ-toulouse.fr/>

The ESPÉ school comprises the three universities of Toulouse. Its main missions are to organise and ensure trainings of students interested in pursuing careers in middle and high schools, as well as to provide support for life-long learning to senior teachers.

My contributions: the working group I coordinate focuses on innovative technologies that can be used to promote and facilitate human learning through the coordination, support and evaluation of face-to-face, distant or blended pedagogical situations. My activities thus relate on the organization and management of plenary sessions where experts expose teaching and/or learning tools, but also on the dissemination of these tools within the ESPÉ community.

2008 - 2010 **Technical coordinator of the ARIADNE Foundation.**

<http://www.ariadne-eu.org/>

The ARIADNE general description appears in the previous section.

My contributions: I coordinated the strategy to adopt regarding software architectures and technologies (to be) implemented within the existing and upcoming tools of the Foundation. To successfully reach this objective, I scheduled and animated monthly virtual meetings with the geographically distributed developers involved in the design, enhancement and maintenance of the ARIADNE tools.

Conference and workshop organization

2019 14th European Conference on Technology Enhanced Learning. *175 attendees.*
Delft, The Netherlands.

<http://ectel2019.httc.de/index.php?id=918>

Co-program chair.

9th Conference on Environnements Informatiques pour l'Apprentissage Humain. *252 attendees.*

Paris, France.

<https://eiah2019.sciencesconf.org/>

Co-program chair.

Workshop on Apprentissage de la pensée informatique de la maternelle à l'Université : retours d'expériences et passage à l'échelle. *32 attendees.*

Paris, France.

<https://wikis.univ-lille.fr/computational-teaching/wiki/actions/>

- 2019/eiah19/home
Co-chair of the organization committee.
- 2018** 13th European Conference on Technology Enhanced Learning. *Around 150 attendees.*
Leeds, United Kingdom.
<http://ectel2018.httc.de/index.php?id=805>
Co-chair of Workshop.
- Workshop on Organisation et suivi des activités d'apprentissage de l'informatique : outils, modèles et expériences. *29 attendees.*
Besançon, France.
<https://wikis.univ-lille.fr/computational-teaching/wiki/actions/2018/rjceiah/home>
Co-chair of the organization committee.
- 2017** 12th European Conference on Technology Enhanced Learning (EC-TEL). *Around 160 attendees.*
Tallinn, Estonia.
<http://ectel2017.httc.de/index.php?id=777>
Co-chair of Poster and Demonstration.
- 1st ORPHEE Rendez-Vous. *94 attendees.*
Font-Romeu, France.
<http://orphee-edu.fr/orphee-rendez-vous-2017>
Chair of the local organization committee.
- Workshop on Apprentissage de la pensée informatique de la maternelle à l'Université : recherches, pratiques et méthodes. *37 attendees.*
Strasbourg, France.
<https://wikis.univ-lille.fr/computational-teaching/wiki/actions/2017/aia-eiah/home>
Co-chair of the organization committee.
- 2013** 6th Conference on Environnements Informatiques pour l'Apprentissage Humain (EIAH). *177 attendees.*
Toulouse, France.
<http://www.irit.fr/EIAH2013/>
Member of the local organization committee.
- 2009** ARIADNE workshop, 4th Latin American Conference on Learning Objects and Technology Enhanced Learning (LACLO 2009). *23 attendees.*
Merida, Mexico.
<http://www.laclo.org/index.php/conferencias>
Chair.
- 2008** 6th International Conferences on Human System Learning (ICHSL6).
Toulouse, France.

<http://europia.org/ICHSL6/>

Member of the local organization committee.

2007

1st International DMTF Academic Alliance Workshop on Systems and Virtualization Management: Standards and the Cloud (SVM07).

Toulouse, France.

<http://dmtf.org/svm07>

Member of the local organization committee.

Program committee and review

Book chapters Recommender Systems for Technology Enhanced Learning: Research Trends & Applications.

Eds.: Manouselis, N., Verbert, K., Drachsler, H., and Santos, O.C.

Reviewer: 2013.

Educational Recommender Systems and Technologies: Practices and Challenges.

Eds.: Santos, O.C. and Boticario, J.G.

Reviewer: 2011.

Journals

Computers & Education.

Reviewer: 2020.

American Journal of Electrical and Electronic Engineering (AJEEE).

Reviewer: 2017.

Electronic Journal of e-Learning (EJEL).

Reviewer committee member: since 2016.

IEEE Transaction on Learning Technologies (IEEE TLT).

Reviewer: 2014, 2016.

International Journal of Technology Enhanced Learning (IJTEL).

Reviewer: 2012, 2016.

Electronic Journal of e-Learning (EJEL).

Review committee member: since 2016.

Sciences et Technologies de l'Information et de la Communication pour l'Education et la Formation (STICEF).

Review committee member: since 2016.

International Journal of Information Technology and Decision Making (IJITDM).

Reviewer: 2014.

International Journal of Metadata, Semantics and Ontologies (IJMSO).
Reviewer: 2012.

International Journal on Advances in Life Sciences.
Editorial board member: since 2012.

International Journal on Advances in Telecommunications.
Editorial board member: since 2012.

I. conferences Learning Analytics & Knowledge Conference (LAK).
Program committee member: since 2020.

Computer Supported Collaborative Learning (CSCL).
Reviewer: 2019.

European Conference on Technology Enhanced Learning (EC-TEL).
Program committee member: since 2017.

International Conference on Advanced Technologies Enhancing Education (ICAT2E).
Program committee member: since 2017.

Frontiers in Education (FIE).
Reviewer: 2016, 2017.

1st International Workshop on Learning Analytics in practice: Challenges, Visions, Solutions.
Reviewer: 2016.

Remote Engineering and Virtual Instrumentation (REV).
Reviewer: 2016, 2017.

International Conferences on Pervasive Patterns and Applications (PATTERNS).
Program committee member: since 2015.

IEEE International Conference on Advanced Learning Technologies (ICALT).
Program committee member: since 2014.

Workshop on Recommender Systems for Technology Enhanced Learning (RecSysTEL).
Program committee member: 2010, 2012, 2013.

Latin American Conference on Learning Objects and Technologies (LACLO).

Program committee member: 2012, 2013.

Workshop on Contextualized Usage and Attention Metadata: Towards Unobtrusive Context Creation and Usage in enriched Platforms (TUCCUP).
Program committee member: 2011.

Datasets for Recommender Systems in Technology-Enhanced Learning (dataTEL).
Program committee member: 2011.

Metadata & Semantics for Learning Infrastructures at MTSR 2011.
Program committee member: 2011.

Advanced International Conference on Telecommunications (AICT).
Program committee member: since 2009.

International Conference on Mobile, Hybrid, and On-line Learning (eL&mL).
Program committee member: since 2009.

N. conferences PédagoTICE : Pédagogie et Numérique (PédagoTICE 2017).
Program committee member: 2017.

Workshop on "L'évaluation formative pratiquée en classe ou en amphithéâtre"
(ORPHEE RDV 2017).
Program committee member: 2017.

Workshop on "Personnalisation et adaptation dans les environnements
d'apprentissage : un regard interdisciplinaire sur les perspectives de recherche"
(ORPHEE RDV 2017).
Program committee member: 2017.

Environnements Informatiques pour l'Apprentissage Humain (EIAH).
Program committee member: since 2013.

Rencontres Jeunes Chercheurs en EIAH (RJC EIAH).
Program committee member: since 2014.

Colloque International sur l'Innovation Pédagogique (CIIP).
Program committee member: 2014.

Workshop on "Partager des données d'observation pour la recherche en
EIAH: traces d'activité d'apprentissage", EIAH 2011.
Program committee member: 2011.

Workshop on Environnements Mobiles et Apprentissage Pervasif (EMAP).
Program committee member: 2008.

Member of PhD thesis committee

- 2019** Alexis Lebis.
Examiner. May, 22.
- 2017** Rémi Venant.
Co-supervisor. December, 8.
- 2016** José Eder Guzman Mendoza.
Examiner. February, 5.
- 2015** Franck Silvestre.
Co-supervisor. November, 25.
- 2014** Antoine Toueir.
Co-supervisor. November, 28.
- 2013** Valentin Butoianu.
Co-supervisor. April, 4.
- 2012** Mohammed El-Amine Bouabid.
Co-supervisor. December, 7.
- 2008** Olivier Catteau.
Co-supervisor. December, 2.

Scientific Expertise

- 2020** Member of the committee hiring a *Contrat Temporaire d'Enseignement et de Recherche* position.
Université du Maine, Le Mans, France.
- 2019 - present** Member of the follower committee of a PhD thesis.
Université du Maine, Le Mans, France.
- 2017 - 2018** Direction du Numérique pour l'Éducation.
Member of the working group responsible for identifying the tools and technologies dedicated to Learning Analytics.
- 2016 - 2018** Member of the follower committee of a PhD thesis.
Université Claude Bernard Lyon 1, Lyon, France.
- 2017** Reviewer of a research project proposal.
Research Foundation Flanders (FWO), Belgium.
- Reviewer of a research project proposal.
FR-EDUC, École Supérieure du Professorat et de l'Éducation, Franche-Comté, France.
- 2016** Reviewer of a research project proposal.
Research Foundation Flanders (FWO), Belgium.

2012 - 2014 Member of the follower committee of a PhD thesis.
 Université du Maine, Le Mans, France.

Supervision of Postdoctoral students

2019 - 2020 **Anis Bey.** *12 months.*
 Institut de Recherche en Informatique de Toulouse, France.

2017 - 2018 **Jaime Muñoz-Arteaga.** *12 months.*
 Universidad Autónoma de Aguascalientes, Mexico.

Teaching Activities

Current classes

I currently teach around 360 hours per year. The table below summarises the courses I give.

Training programme	Level	Discipline	L	TC	HL
Computer Science department	1 st year	Introduction to computer systems	■	■	■
		Network architecture		■	■
	2 nd year	Network services		■	■
		Client-side web programming	■		■
		Server-side web programming	■		■
		Tutorial projects		■	
		Internship tutoring		■	
		Bachelor GTIDM	3 rd year	Web and REST services	■
	Tutorial projects			■	
	Co-op students			■	
Bachelor DQL	3 rd year	Web programming	■		■
Master MEEF	5 th year	Technology-enhanced learning	■		

L: lectures – TC: tutorial classes – HL: hands-on laboratory

2016 - present **Technology-enhanced learning (fifth year).** *Coordinator.*
 10h. of lectures (15 students).
Contents: introduction to technology-enhanced learning, e-learning standards, trace-based systems.

2014 - present **Network services (second year).** *Coordinator.*
 10h. of tutorial classes, 9h. of hands-on laboratory (28 students).
Contents: network interconnections, network address and port translation, firewall and security awareness (iptables, DMZ), installation and configuration of basic network services (SSH, FTP, NFS, DHCP).
Note: since September 2014, the remote laboratory resulting from my research

activities is made available to students for this learning unit.

Client-side web programming (second year). *Coordinator.*

10h. of lectures, 20h. of hands-on laboratory (56/28 students).

Contents: document object model (DOM), DOM dynamic management, event-driven programming (Javascript), asynchronous requests (Ajax), toolkit for easy programming (jQuery).

Web and REST services (third year). *Coordinator.*

6h. of lectures, 12h. of hands-on laboratory (20 students).

Contents: client/server architecture, remote procedure call, simple object access protocol, web service description language, universal description discovery and integration, discovery and integration, resource-oriented architecture.

Web programming (third year). *Coordinator.*

10h. of lectures, 20h. of hands-on laboratory (56/28 students).

Contents: server- and client-side programming, Apache/PHP/MySQL, application structure (MVC), security issues (SQL injection, XSS, CSRF, cross-site cooking), event-driven programming (Javascript), asynchronous requests (Ajax), toolkit for easy programming (jQuery).

2013 - present Server-side web programming (second year). *Coordinator.*

13h. of lectures, 27h. of hands-on laboratory (108/28 students).

Contents: client-server and three-tier architectures, web server (Apache), dynamic web pages (PHP), data management (MySQL), application structure (MVC), security issues (SQL injection, XSS, CSRF, cross-site cooking).

Introduction to computer systems (first year). *Coordinator.*

4,5h. of lectures, 18h. of tutorial classes, 25h. of hands-on laboratory (160/28/16 students).

Contents: operating system architecture, information coding, command language, Shell scripts, management of files/process/users, installation and configuration of an operating system (Linux Debian).

Note: since September 2014, the remote laboratory resulting from my research activities is made available to students for this learning unit.

2006 - present Tutorial projects (second year, bachelor degree).

15h.+16h. of tutorial classes (32 students).

Contents: software development process (specification, design and architecture, test, debugging and documentation), tasks repartition among the students and scheduling, elaboration of a synthetic talk.

Internship tutoring (second year, bachelor degree).

10h.+10h. of tutorial classes (8 students).

Contents: work within an enterprise or organisation, writing of a report, elaboration of a synthetic talk.

Network architectures (first year).

10h. of tutorial classes, 10h. of hands-on laboratory (27 students).

Contents: OSI model, local area networks, data link layer protocols (Ethernet, WiFi), spanning tree protocol, Internet protocol (address, routing table), transmission control protocol, network-related commands.

Innovative technologies for teaching

2015 - present Tsaap-Notes (and Elaastic): a collaborative platform for formative assessments.

This web-based system resulting from my research works allows teachers to easily integrate formative assessments into their face-to-face lectures. I use this tool with my students in several learning units, and thus encourage peer instruction as well as discussions with them.

2014 - present Lab4CE: a remote laboratory for computer education.

A web-based platform resulting from my research works is available to students within several learning units related to system and network administration. Students are able to finish their practical work at anytime, from anywhere, using any device connected to the Internet.

2006 - present Moodle: online teaching and learning.

I use Moodle to make educational resources available online, to create assessments and formative questionnaires, and to exchange ideas and information with colleagues and students.

2005 - 2016 Distant tutoring.

International E-MIAGE (bachelor degree), University of Toulouse.

Collective responsibilities

2018 - present Coordinator of the curriculum *Diplôme Inter-Universitaire Enseigner l'Informatique au Lycée.*

Université Toulouse III – Paul Sabatier.

2015 - present Elected member of the Administrative Council.

Institute of Technology of Toulouse.

2013 - present Pedagogical coordinator of the topics “Web, Internet, Mobility”.

Computer Science Department, Institute of Technology.

2010 - present Elected member of the Computer Science Department’s council.

Computer Science Department, Institute of Technology.

2007 - present Coordinator of the E-learning activities.

Computer Science Department, Institute of Technology.

Co-supervision of PhD students

I co-supervised 6 PhD thesis that have been defended. I am currently co-supervising 1 PhD thesis, and supervising 1 PhD thesis.

2019 - present **Louis Sablayrolles.**

Title: *Un système d'apprentissage automatique pour la personnalisation et la régulation des activités des apprenants en fonction de leurs compétences et de leurs objectifs.*

Advisor: Nathalie Guin.

Co-supervisor: Marie Lefevre.

2019 - present **Rialy Andriamizeza.**

Title: *Conception d'un système interactif dédié aux évaluations formatives et dirigé par les Learning Analytics.*

Co-supervisor: Franck Silvestre.

2014 - 2017 **Rémi Venant.**

Defended on November 25 at IRIT Lab.

Title: *Les learning analytics pour promouvoir l'engagement et la réflexion des apprenants en situation d'apprentissage pratique.*

Advisor: Prof. Philippe Vidal.

Committee: Prof. Vanda Luengo, Prof. Sébastien George, Prof. Pierre Dillenbourg, Prof. Eric Sanchez, Dr. Jean-Charles Marty, Dr. Daniel Marquié.

Current position: Associate Professor at Université du Maine.

2012 - 2015 **Franck Silvestre.**

Defended on November 25 at IRIT Lab.

Title: *Génération automatique de tests d'auto-évaluation personnalisés pourvus de feedback résultant de la prise de notes collaborative.*

Advisor: Prof. Philippe Vidal.

Committee: Prof. Pierre Tchounikine, Prof. Serge Garlatti, Prof. Sébastien George, Prof. Thierry Nodenot.

Current position: Associate Professor at University of Toulouse 1 – Capitole.

2010 - 2014 **Antoine Toueir.**

Defended on November 28 at IRIT Lab.

Title: *Une démarche méthodologique orientée-but pour la conception d'une surveillance auto-gérée dans les systèmes autonomes.*

Advisor: Prof. Michelle Sibilla.

Committee: Prof. Omar Cherkaoui, Prof. Carlos Westphall, Prof. Jean-Michel Bruel, Dr. Guillaume Doyen.

Current position: Volunteer, Médecins Sans Frontières (MSF).

2008 - 2013 **Valentin Butoianu.**

Defended on April 4 at IRIT Lab.

Title: *Share and reuse of context metadata resulting from interactions between users and heterogeneous web-based learning environments.*

Advisor: Prof. Philippe Vidal.

Committee: Prof. Thierry Nodenot, Prof. Serge Garlatti, Prof. Alain Mille, Dr. Christophe Reffay.

Current position: Research and development engineer, Orange Toulouse.

2006 - 2012

Mohamed El-Amine Bouabid.

Defended on December 7 at IRIT Lab.

Title: *De la conception à l'exploitation des travaux pratiques en ligne: application d'une approche générique à l'enseignement de l'informatique.*

Advisor: Prof. Philippe Vidal.

Committee: Prof. Christophe Choquet, Prof. Sébastien George, Prof. Jean-Marc Labat, Dr. Ferhat Khenak.

Current position: Research and development engineer, CERIST Alger.

2005 - 2008

Olivier Catteau.

Defended on December 2 at IRIT Lab.

Title: *Le cycle de vie de l'objet pédagogique et de ses métadonnées.*

Advisor: Prof. Philippe Vidal.

Committee: Prof. Yolaine Bourda, Prof. Monique Grandbastien, Prof. Brigitte De la Passardière, Dr. Daniel Marquié.

Current position: Associate Professor at Université Toulouse III – Paul Sabatier.

Supervision of Research Master students

2020

Maxime Durand.

Master in Human Computer Interaction, ENAC, Toulouse.

Title: *Design and implementation of an interactive dashboard for supporting students' self-regulated learning in competence-based learning environments.*

2018

Clément Hérouard.

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Title: *Analyse sémantique des productions des apprenants : création d'un indicateur sémantique pour des scripts Bash.*

2015

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Title: *Management of ludic learning objects to support children with reading problems.*

2014

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Title: *Vers une orientation personnalisée des apprenants fondée sur les compétences.*

2010

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Research Master in Computer Science and Telecommunications, University of

Toulouse.

Title: *Etude de l'activité de surveillance pour un middleware orienté QoS.*

2008

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Title: *Automatisation de tâches dans un environnement d'apprentissage en ligne – le cas des ressources pédagogiques.*

2007

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Research Master in Computer Science, University of Toulouse III.

Title: *Gestion des traces d'activités des utilisateurs au sein d'un système d'apprentissage – le cas d'un outil de traitement de texte.*

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Master ASIC, University of Toulouse.

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INSA, University of Toulouse III.

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Part II

Research Works

Introduction

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This manuscript gives an overview of the research we¹ conducted in the field of technology supporting education. The research was mainly conducted in the laboratory *Institut de Recherche en Informatique de Toulouse*, France, with the collaboration of students and colleagues from Europe and Latin America.

Research context

Educational research is multidisciplinary and requires the collaboration of researchers from various fields such as educational sciences, psychology, didactics, ergonomics or cognitive sciences. When technology comes into the educational frame, experts in digital technologies are needed for strengthening the link between technology and human sciences theories and methodologies. Before going into the details of the research areas we investigated, we expose in this section the main advances and approaches in information technology that influenced teaching and learning over the last century. These major transformations, as well as the predominant underlying theories of learning, are summarised in Figure 1.

¹"We" is used in this document to refer to the works achieved by myself together with my colleagues. "I" is used in the research programme section, as it deals with my own research perspectives.

Technology for education

In his paper "Paradigm shifts and instructional technology: An introduction", [Koschmann \(1996\)](#) summarises the evolution of technology for education as a set of paradigm shifts that started from (1) instructional programming, based on behaviourist theories; continued with (2) intelligent tutoring systems, based on cognitivism; and (3) the LOGO paradigm, based on more constructivist theories; to (4) computer supported collaborative learning, based on socio-cognitive theories.

Between the 1950s and 1960s, behaviourism was the predominant theory, and technologies were mainly used as a support for instruction. Instructional programming includes programmed instruction and computer-assisted instruction, both based on instructivist pedagogy which claims that learning is best accomplished by small incremental steps with immediate reinforcement or reward for the learner. First networked educational system such as PLATO emerged in the 1970s, together with Intelligent Tutoring Systems (ITS) based on the idea that artificial intelligence could serve to model cognitive processes. Other systems such as LOGO included microworlds to offer students the opportunity of becoming active in their learning by manipulating the learning environment rather than observing phenomena. Then, microcomputers and computer terminals have been deployed at scale in the 1980s. This massive introduction of computers in education opened up new opportunities for interactivity-rich material such as hypertext documents used to explore and search information, or structure knowledge. The 1990s have seen the advent of the World Wide Web. Online learning, or e-learning, refers to a way of instruction based on the connectivity allowed by Internet, and the access to information. With e-learning, full curriculum and learning materials are available online to users from anywhere at any time.

Later on, the diversity of learning environments raised in the 2000s the need for standard solutions. Some initiatives described learning resources to facilitate cataloging, searching and reuse of this type of material, and others were developed to orchestrate learning scenarios. Also, the fast development of mobile devices in the mid-2000s made researchers investigate contextual learning to deliver the best learning experiences according to the context in which learning takes place. Finally, the appearance of MOOCs led to the theory of connectivism in which learners learn in connection from others.

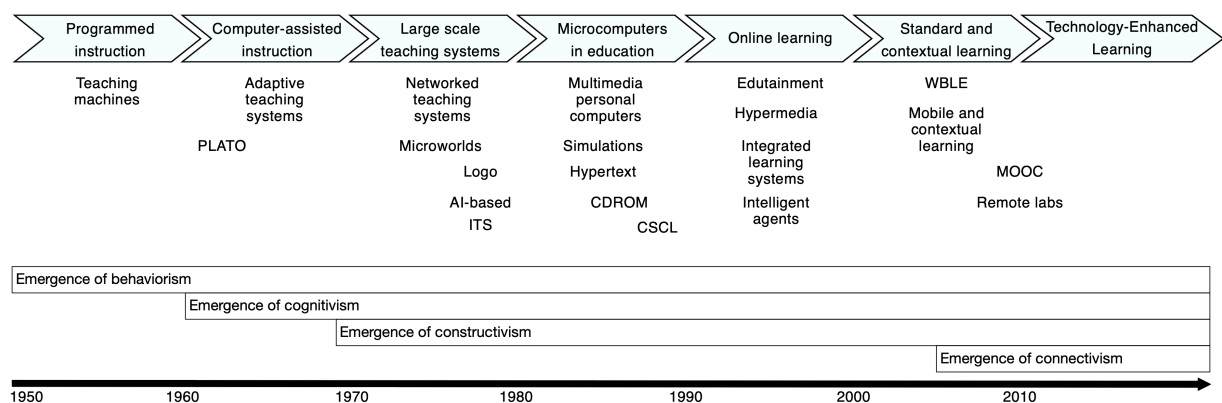


Figure 1. Advances of technology for education.

Technology-enhanced learning

Along with the growing adoption of e-learning, the term "Technology-Enhanced Learning" (TEL) appeared in the mid-2000s to denote more advanced or alternative practices of technology for teaching and learning. Whereas systems devoted to education were mainly used for online learning in the 1990s, blended learning conditions, which can be defined as a pedagogical approach combining traditional face-to-face teaching methods with additional online learning material and opportunities, are nowadays commonly used in almost every educational institutions ([Garrison and Kanuka, 2004](#)). With TEL, learning can take place anywhere in flexible learning spaces in which students might use multiple personal technologies to access to personal learning environments. This differs from technological practices in which learning took place only in computer- and media-equipped teaching classrooms featuring virtual learning environments. In Europe, financial support to advance the development of educational technologies raised significantly in the mid-2000s through Networks of Excellence (NoE) whose primary goal was to strengthen emerging research areas. Prolearn, Kaleidoscope or Stellar are examples of such NoE which significantly contributed to the development of TEL. These investments notably advanced social-constructivist learning by offering the opportunity to build sustainable networks and communities of learners and practitioners.

Although there is not a single definition of TEL, the expression "Technology-Enhanced Learning" is now adopted world-wide by the research community to refer to the use of technology to provide solutions to current challenges facing the educational arena, from the implementation of large-scale scenarios and access to knowledge for all, to individualisation and personalisation of trainings, or lifelong learning. Based on the definition by [Spaulding \(2012\)](#), in this document we consider TEL as the use of technology to provide both individuals and institutions with social and technical innovations for learning and teaching practices, whether these practices occur in face-to-face, online or blended settings. TEL solutions, when designed intentionally for solving actual educational problems, become an essential support for all educational stakeholders, from learners and teachers to engineers, training managers and decision-makers.

Nowadays, the use of technologies is spread through all types of education, formal and informal, and for all educational levels, from elementary school to professional learning. However, the research presented in this document is framed in the field of higher education. TEL adoption in higher education has been slow due to the (very) expensive cost of effective solutions ([Bishop and Verleger, 2013](#)), but also because "*sustainable change is not a simple matter of product development, testing and roll-out*" ([Scanlon et al., 2013](#), p. 6). However, development of digital technologies to support education has severely increased over the past decade as research has made significant advances. TEL is nowadays implemented in almost all higher education institutions (HEI) to support and enhance traditional teaching and learning practices, but also to propose new innovative practices that cannot be implemented without digital support. In the private sector as well, significant investments are made over Europe to develop TEL ([Brighteye Ventures, 2019](#)). Historically, the United Kingdom and the Nordic countries have been the strongest regions in Europe in terms of Ed Tech investment. These countries have high broadband and device penetration both at home and school, providing fertile ground to test and deploy educational solutions over time. In the rest of Europe, most Ed Tech funding is geared at bridging the divide between the 21st century skills required by the labour market and the skills being provided by academic institutions. Three new players have emerged over the last six years: Germany, France,

and to some extent Spain. Between 2014 and 2018, these countries have seen an increase in Ed Tech investments of 135%, 133% and 60% respectively. For example, the French start-up OpenClassrooms² raised \$60M from US PE fund General Atlantic in 2018, and now delivers online degrees in software development, data science and other in-demand skills.

Research areas and objectives

Among the broad diversity of topics addressed within the TEL area, our research contributes to three major international challenges highlighted in 2017 by Sharples in the context of higher education (2017): open and global education; development of education for the future; and efficient education.

Open and global education

Globalisation has raised the need for global education. Global education addresses topics such as human rights, sustainability or intercultural communication, and is based on universal values including equality, diversity, co-operation and inclusion. UNESCO defines global education as "*a form of education which [...] develops the skills, attitudes and values which enable people to work together to bring about change and take control of their own lives. [...] Global education places particular emphasis on curriculum process as well as content*" (UNESCO, 2009a). Our works relied on two facets of global education: (1) metadata for Open Educational Resources (OER) to support their management and enhance their quality in a widely distributed and collaborative context, and (2) competence-based approaches to better align training programmes with business requirements and foster mobility and exchanges of workers in a constantly moving labour market.

Metadata for open educational resources. Metadata are defined as data that provide information about other data (Merriam-Webster, 2015). Metadata give details about several facets of numeric data, and range from descriptive (e.g. title, abstract, description) or technical (e.g. file type, creation and modification dates, size) descriptors to statistical information (e.g. number of searches, reads, downloads). In the TEL context, metadata gained popularity in the early 2000s with European projects such as ARIADNE I and ARIADNE II. The primary objective of educational metadata is to describe as exhaustively as possible educational content to facilitate various processes such as search and discovery, acquisition, evaluation, or (dis)aggregation and reuse of learning resources. A number of standards dedicated to open educational resources have been proposed for the last two decades. One of them is the Learning Object Metadata (LOM), which comprises a pool of more than 60 descriptors (IEEE, 2002). It has been widely adopted by a large set of TEL systems and environments, even if numerous web portals not dedicated to education implement the Dublin Core Metadata Element Set (Dublin Core Metadata Initiative, 2004). Another standard is the Metadata for Learning Resources (MLR), developed by the International Organization for Standardization (ISO) and whose data elements have been published in 2015. MLR is intended to support optimal compatibility with both the LOM and Dublin Core and to provide cultural adaptability requirements from a global perspective.

Digital campus delivering online or blended curriculum are nowadays composed of a variety of systems, including authoring and collaborative tools intended to support authors and (graphic)

²<https://openclassrooms.com>

designers to design learning resources; learning object repositories to classify and store learning resources; and virtual learning environments driven by pedagogical engineers and bringing pedagogical services to teachers, learners and tutors. This heterogeneous and distributed computing ecosystem is complex to manage, even more when the various stakeholders are geographically distributed. Even if they provide good practices and benefit from solid operational experiences, the standard initiatives mentioned above lack formal methodologies and user support to overcome the difficulties flowing from such complex settings. Our research related to this area aimed at supporting distributed collaborators who have to work together in highly decentralized settings to design, classify, index and deliver open educational resources across a large set of TEL systems. Specifically, the objective was to define the tasks and objectives that must be achieved in the open educational resource development process, as well as a methodology increasing the quality of both the OER and the overall development process.

Competence-based approach. For several years, educational policies have supported the advancement of Competence-Based Approaches (CBA) in initial and vocational training. The objective of this strategy is to facilitate the development of learners' ability for action and, in the longer term, enhancement of their autonomy. In France, for example, competence-based approaches are used at different levels of education to design tools intended to specify and monitor skills: the "common base of knowledge and skills"³ and the "personal skills booklet"⁴ for elementary and high schools, or the "portfolio of experiences and skills"⁵ for higher education. In the educational context, CBA has changed pedagogical methods by introducing, for example, more problem solving and inquiry-based activities, but training strategies remain diverse and uncorrelated with reference frameworks (Mina, 2014). Companies have also adopted this approach for training plan. Human Resources and Knowledge Management departments have started to set up jobs and skills management systems to specify the objectives of an organisation in terms of skills, and to monitor collaborators' profiles in terms of level of expertise.

The competence-based approach has been and is still subject to controversy, especially in the educational sciences community (Crahay, 2006; Hirtt, 2009). Our works build upon the idea that competence is a mean for connecting higher education and labour market demands, since both the educational and professional sectors develop competence-based approaches. In this context, our objective has been to study how technology could support competence-based approaches to provide common references to both training and business sectors. Among the five steps of the competence development defined by Sinnott et al. (2002), our works address analysis of the gap between existing competences and those required for a specific position, and the identification of training programmes to reduce the identified gaps. On the one hand, our research has focused on facilitating the design of competence-based curriculum in order to make them meaningful from a global perspective. On the other hand, we have also pursued offering companies the opportunity to identify the training programmes that best suit their needs in terms of competences. Our works have intended to better serve different stakeholders: learners, so they can easily identify the curriculum that best fit the professional life they wish to engage in; training programme managers, so they can design curriculum according to the labour market demand; employees, so they can be aware of the competences they master and more easily move towards more advanced or complementary skills; and human resources directors, so they are able to identify training

³*Socle commun de connaissances et de compétences* in French

⁴*Livret personnel de compétences* in French

⁵*Portefeuille d'expériences et de compétences* in French

programmes that fit the skills required to sustain and enhance the operational status of their company.

Adaptive learning for personalised learning experience

Even if the expression "user experience" (UX) appeared in the early 20th century with Taylor and Ford who investigated how to increase efficiency and production of human labour, it became commonly used from the mid-1990s with the work by Norman (1988). This cognitive sciences researcher claimed that an exemplary UX for a product or service meets the exact needs of the user, while providing joy when owning and using this product or service. In computer science, the international standard on ergonomics of human-system interaction defines user experience as the "*person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service*" (International Organization for Standardization, 2010). Such a general definition led to a wide range of more specific proposals, but the interdisciplinary, methodological and conceptual complexities of UX still prevent the various communities of research to establish a joint definition. However, Law et al. (2009) showed that a number of researchers agree on the UX definition given by (Hassenzahl and Tractinsky, 2006, p. 95): "*a consequence of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.) and the context (or the environment) within which the interaction occurs (e.g. organisational/social setting, meaningfulness of the activity, voluntariness of use, etc.)*". All contributions in this document build upon this understanding of user experience.

In TEL, this definition has been adapted to the learning context as "*any interaction, course, program, or other experience in which learning takes place, whether it occurs in traditional academic settings (schools, classrooms) or nontraditional settings (outside-of-school locations, outdoor environments), or whether it includes traditional educational interactions (students learning from teachers and professors) or nontraditional interactions (students learning through games and interactive software applications)*" (The Glossary of Education Reform, 2013). This definition embraces any experience triggering learning, whether it takes place indoor or outdoor, inside or outside the classroom, and whether interactions involve human or computers. Among the various approaches explored by the TEL research community to enhance learning experience, adaptation of learning systems represents the focus of a large set of studies. Adaptive learning aims to provide users, whether they are teacher, learner, tutor or decision maker, with a learning environment that fits as closely as possible their individual needs and expectations.

We have worked on providing users with personalised learning experience based on adaptation of digital learning environments. Adaptation highly relies on information reflecting users' learning expectations, knowledge, preferences, or activities. Such information might be explicit self-reported data gathered, for instance, through questionnaires delivered to users, and implicit interaction data gathered automatically by a system. The works we have conducted focus on this second type of data, and aim at proposing a quality-oriented framework able to collect information describing users' learning experience. Specifically, we have adopted the learning experience classification by Hassenzahl and Tractinsky (2006) which identifies three main categories of factors influencing user experience: user, system properties, and usage context. Even if our overall objective is to consider both traditional and nontraditional settings and interactions, our works have focused so far on human-computer experiences, i.e. users interacting with software appli-

cations. In this sense, we have considered user learning experience as a result of interactions between educational stakeholders, digital learning environments, and usage of these systems by users. The first factor denotes user's expectations, needs, preferences, motivations and emotional states; the learning environment relates to digital systems, resources and services offered to users during their learning experience; the usage context refers to activities that have been carried out by users on learning environments. In our works, it has been key to investigate how to gather data reflecting significant characteristics of these factors, and we conducted our research with two strong requirements in mind: to propose solutions that are as generic as possible while remaining understandable and usable by a computer, and to ensure the quality of the monitoring process responsible for gathering data.

Active learning to promote efficient education

Active learning strives to make students real actors of their learning. When this strategy is implemented in the classroom, learners are not passive listeners receiving knowledge delivered by teachers, instead they become active participants in the process of building and reflecting about knowledge. Active learning refers, in the remaining of this document, to the definition by Prince (2004, p. 223): "*active learning requires students to do meaningful learning activities and think about what they are doing*". The efficiency of this form of learning in Science, Technology, Engineering, and Mathematics (STEM) disciplines has been claimed by a wide variety of (empirical) studies and meta analysis whose results showed (i) an increase of students' performance and achievement (Hoellwarth and Moelter, 2011; Freeman et al., 2014), (ii) an improvement in student engagement (Marrone et al., 2018) and retention (Subramanian et al., 2012), (iii) a stronger mobilisation of higher-order thinking skills (Kim et al., 2013), or (iv) a development of 21st century skills (Romero et al., 2015). Among the common forms of active learning including flipped classroom, problem-based learning or game-based learning, we have investigated the Think-Pair-Share (TPS) strategy and inquiry-based learning for developing effective education.

Think-Pair-Share. This collaborative learning approach requires students to individually answer to a question, then discuss in groups of four-max peers about their answers to formulate a collective answer, and then share their thinking or ideas with the whole class (Lyman, 1987). Prior research showed that, when experimented in classrooms with small groups of individuals, the Think-Pair-Share strategy allows students to develop their critical thinking skills (Kaddoura, 2013), express their reasoning and get immediate feedback on their understanding (Carss, 2007). Our objective was to explore how technology can support the design and implementation of TPS strategies with large groups of students in complex learning settings. In particular, we conducted a research that aimed at designing a formative assessment tool featuring TPS strategies, and that can be used in large face-to-face, online and blended settings. We aimed at engaging students as much as possible in formative assessment activities, as this type of activity increases time on task (Cook et al., 2010), provides learners with timely feedback (Andrade and Heritage, 2017), and prevents procrastination (Arnold, 2016).

Inquiry-based learning. This active learning strategy is a space where students can formulate their own questions, define a hypothesis, conduct experiments and interpret the data. Experiments are central to this form of learning, as students are able to test their understandings upon real-world objects and phenomena. In STEM disciplines, higher education institutions usually supply laboratory classes as a physical space that hosts specific apparatus to run ex-

periments. However, experiments can also be conducted through virtual tools and spaces, also known as remote laboratories, that aim at reproducing the behaviour of physical equipments and elements. Remote laboratories have been investigated for the last decade, and technical solutions are now effective to deliver robust remote inquiry-based learning sessions. These solutions required important efforts from the research community, but less attention has been paid to the learning facet of these systems. Our research aimed at engaging learners in inquiry-based learning activities through the use of remote laboratories, and explored how to enhance these systems with learning-oriented supports. Specifically, our objective was twofold: to provide students with a learning-centred environment available from outside the academic facilities and supporting social interactions between peers and instructors, and to enrich traditional laboratory classes with capabilities that can not be implemented without the use of technology.

Research questions

We adopted a design-based research approach to achieve the objectives mentioned in the previous section, as the solutions we developed have been experimented and evaluated in authentic learning settings. Design-based research (DBR) is defined by Barab and Squire (2004, p. 2) as "*a series of approaches, with the intent of producing new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic settings*". Although DBR is not a methodology itself (Herrington et al., 2007), it is a research approach whose interventions lie within a wide range of methodologies using mixed methods (Anderson and Shattuck, 2012) that has been widely adopted in TEL for analysing the impact of a technology with actual learning contexts. Also, even if our works aimed at bringing solutions as generic as possible, the challenges exposed below have been tackled in STEM disciplines, as they represent our fields of expertise.

Development of open educational resources and global curriculum

The approach we followed to support development of high quality open educational resources within complex ecosystems relies on the management of learning content and metadata lifecycle. For decades, industry has been using project lifecycle methodologies to maximise the quality, production time and cost of products. In computer science, the software development lifecycle (Ruparelia, 2010) is a process that aims at producing high quality software at the lowest cost in the shortest time. To adopt such approaches in the context of open educational resources, we addressed substantial questions in different contributions:

- What are the different phases of the OER lifecycle?
The various learning contexts (i.e. face-to-face, online or blended settings), combined with the complexity of nowadays TEL computing environments, make it difficult to build a common specification covering lifecycle of both learning content and metadata. There has been some research aiming at defining such a lifecycle, but existing approaches are strongly coupled to the learning context in which they have been developed. Also, they stand on different steps and specific vocabulary that introduce heterogeneity in OER management.
- What metadata are required to support the OER lifecycle? How to extend the predominant standards so that they integrate these metadata?

Some standards (e.g. the LOM) include a category dedicated to lifecycle, but the suggested descriptors do not allow for a fine-grained description of the learning object lifecycle. The issue here resides in the specification of the metadata and associated vocabulary required to support the OER lifecycle, but also in the study of the outstanding standards to identify the extensions required to take into account these metadata and vocabulary.

- Who are the stakeholders involved in the OER development process, and what are they responsible for?

Development of open educational resources involve a significant number of stakeholders, especially when technology is used to enhance learning and teaching practices. The challenges to improve the quality of the OER development process are to identify the stakeholders involved in the lifecycle; specify their respective tasks; and identify the lifecycle step(s) during which tasks must be performed.

- How to support stakeholders throughout the entire OER lifecycle?

When used inappropriately, technology might introduce complexification and difficulties in accomplishment of tasks, instead of easing and enhancing the quality of the work performed by users. In the context of OER development, one challenge is to provide the various stakeholders with relevant technological support so that each step of the lifecycle can be handled with increased efficiency and quality.

At a higher level of granularity, development of global curriculum according to a competence-based approach requires to establish a connection between the training and business sectors. In our research, we have been exploring how competences can act as a facilitator and adopted a model-oriented approach to represent in a common way the heterogeneous entities involved in both sectors. We addressed several issues under this main objective:

- What representation of competence should be proposed in order to align the description of both occupations and trainings?

Even if some efforts have been made at the national and international levels to develop common and uniform representation of competences, the resulting standards still suffer from a lack of precision in the analytical description of competences. Also, they often adopt different vocabularies to refer to identical concepts. The challenge was to design a detailed modelling of competence able to express the semantics of the existing initiatives.

- How to make this modelling able to link training programmes to labour market?

The growing interest for competence-based approach in the mid 2000s led to multiple proposals aiming to describe businesses as a set of required competences, whereas other efforts focused on common representation of training programmes. These initiatives remain independent from each other, so the challenge consisted in unifying the representation of both sectors, using competences as a common reference.

- How to exploit the whole model to support the different stakeholders with relevant competence-oriented tools?

Training and business sectors involve a significant number of stakeholders who all require different support, as they achieve distinct tasks and objectives. One main challenge relied on the design of tools that meet the needs of all stakeholders, from learners and training managers to employees and human resources directors.

Quality-oriented management of user learning experience

All our contributions in this area rely on the model-driven approach launched by the Object Management Group (OMG) in the early 2000s. This approach has been successfully implemented in several research areas such as software development, cloud computing or network management. It provides high-level unifying representations of heterogeneous entities, as well as monitoring mechanisms independent from a given technology or implementation. Regarding the modelling of data representing user learning experience, several issues needed to be tackled:

- How to design a learning experience model able to federate highly heterogeneous data while preserving their semantics?
The big set of TEL software and systems available to users makes it very difficult to get an accurate overview of their learning experience. To enhance its exhaustivity and federate heterogeneous TEL artefacts, one of the main issues relied on the design of a unifying learning experience model characterised by a high abstraction level, but also integrating semantic features making the collected data meaningful for adaptive purposes.
- How to support processing and sharing of meaningful indicators?
Adaptation is based on indicators inferred from the collected data, and are usually calculated within personalised environments (i.e. within end-user systems). As a consequence, they are not shared across different applications, and adaptive algorithms can not benefit from a more comprehensive set of input data. One challenge was to integrate the processing of indicators inside the learning experience model, and to offer services facilitating their reuse at a large scale.
- How to ensure privacy of users?
Collecting information about user learning experience faces the recent regulation rules to protect user privacy such as the European General Data Protection Regulation (GDPR). Ensuring privacy of users without restricting the types or amount of valuable information that can be gathered, or indicators that can be processed, represents a crucial issue to address when one intends to enhance the learning experience.

Also, even if the OMG approach natively provides monitoring features, our research has addressed the design of a quality-oriented monitoring system able to ensure the quality of the data describing user learning experience. The derived issues we tackled comprise:

- How to propose a methodological approach able to ensure quality of the monitoring system?
Accuracy and relevance of adaptive algorithms are tightly coupled with the quality of data collected by the monitoring system. The challenge here was to design a methodological approach contributing to the quality of the gathering process. The methodology had to make the monitoring system able to self-react to gathering problems when they occur, or to make sure that data are collected at the right time.
- How to assist human administrators in the design of adaptive monitoring strategies according to quality objectives?
The growing complexity of TEL environments increases the complexity of the monitoring

task. Even if the monitoring system features self-adaptation capabilities, adaptation strategies are defined by human administrators. One challenge we tackled was to propose a set of methods helping administrators to drive self-adaptation of the monitoring system according to their quality objectives.

Design and engineering of engaging TEL processes and systems

Think-Pair-Share strategies implemented in small classrooms allow teachers to engage most of learners in the proposed activities as they can reformulate the question if needed, give individual motivation and specific orientation, or balance participation between students. These strategies can not be instrumented in learning contexts involving a large number of students in online or blended settings. In particular, the following issues were addressed to instrument TPS strategies through a formative assessment system:

- How to adapt the Think-Pair-Share strategy to massive learning settings?
The three phases of the TPS strategy require a number of modifications to be implemented in technology-enhanced massive learning settings. A process had to be defined to automatically pair a large number of learners so they can think about their own knowledge on the basis of peers' understandings. Another difficulty was to provide learners with timely and personalised feedback about their contributions.
- How to implement the matching process into a formative assessment tool?
The issue here was twofold. At a macro level, the challenge was to orchestrate the sequence of activities comprised in the TPS strategy. At a micro level, the challenge was to design a system engaging students in the TPS activities as much as possible, i.e. at least as much as their level of engagement in small classroom settings.

Regarding the other form of active learning in our focus, we investigated inquiry learning in the context of computer education. At a first sight, if this discipline might look easy to instrument in a remote setting, a closer look shows that a number of challenges have to be tackled, especially when the objective is to develop innovative learning scaffolds and capacities:

- How to design an engaging remote laboratory environment?
Computer education is often based on virtualisation tools to provide users with pre-configured virtual machines comprising the set of software they need to perform their learning task. Virtualisation tools are complex environments requiring advanced competences in system and network administration. One issue to promote engagement of users, including teachers, in inquiry-based activities, was to build a remote laboratory environment hiding the complexity of the whole framework and providing tools as easy to use as possible.
- How to promote social interactions in remote laboratories?
Social interactions play a crucial role during face-to-face inquiry learning sessions as learners are used to talk with each other to ask questions, share ideas and understandings, look at the work achieved by peers, or explain a solution to a problem. This type of interaction is tightly coupled to awareness of learners regarding their peers, environment, or performance.

In remote inquiry learning settings, one challenge relates to the design of innovative methods and techniques to provide learners with scaffolding tools increasing both individual and collective awareness.

- How to instrument collective forms of learning into remote laboratories?

In traditional face-to-face laboratory sessions, inquiry learning often occurs in small groups where students interact with each other to explore how to solve the given problem. Their interactions implicitly implement different types of instruction such as collaboration, cooperation or peer tutoring. When remote settings are used, one challenge is to provide features allowing learners to achieve tasks collectively, and tutors to monitor students interactions so they are able to intervene when needed.

Overview of the main contributions

An overview of our contributions addressing the research questions above is given in Figure 2.

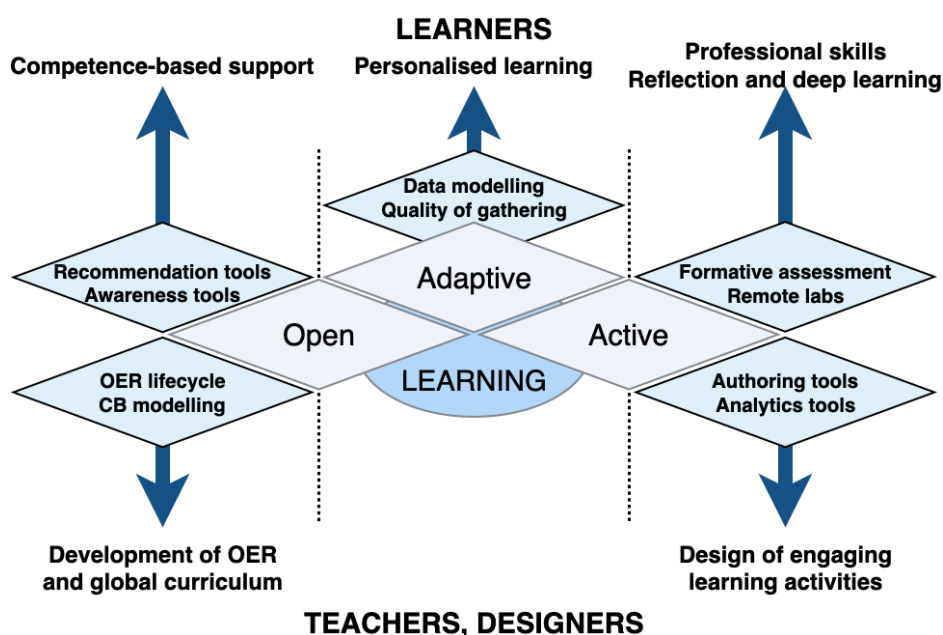


Figure 2. Overview of our contributions.

Development of open educational resources and global curriculum. Open education has been abstracted by Stracke (2016) into three different dimensions: legal, visionary and operational. Our work falls into one facet of the operational dimension and contributes to the development of high quality open educational resources. Two main contributions have been developed in this area. The first contribution was the design of a common OER lifecycle combined with a methodology allowing for progressive, semi-automatic and role-based metadata generation contributing to the quality of each step of the lifecycle. The second contribution relied on the set of tools supporting users in the management of the OER lifecycle. The toolkit includes visualisations providing authors, pedagogical engineers and managers with awareness about the progress of the OER development process, or about the divergences between learning resources

deployed in several systems. We implemented our approach with an existing standard (i.e. the LOM) and conducted an experiment with a French digital campus.

Also, to offer global competitive trainings, we have developed two main contributions. The first one was a representation of competence able to federate existing initiatives from both academic and professional areas, and integrating standardised competence frameworks. This competence-based modelling approach unifies learners' profiles, trainings and businesses, and offers a shared reference to bridge the gap between these two sectors. The second contribution on development of global curriculum was the scaffolding tools intended for learners and teachers. We provided learners with awareness about their profile in terms of competences, but also with recommendations about the training programmes matching with the jobs they are likely to embrace. We also proposed an authoring tool for supporting teachers in the design of competence-based curricula, and another one that automatically generates the syllabus of a training programme including the expected learning outcomes.

Quality-oriented management of user learning experience. In the area of personalised learning, our works have until now focused on the primary step of any intelligent or adaptive technology: the data gathering process, considered by Pasquale (2017) as essential to the artificial intelligence vision of automation. Our first contribution was related to a privacy-enabled framework able to capture information about learning experiences of users. Our approach, based on an open standard dedicated to system and application management, proposed a high resolution model of user learning experience and introduced a privacy-aware architecture where sensitive and non-sensitive data are stored in different locations. The model integrates data resulting from direct interactions between users and TEL software, but also supports indicators inferred on the basis of the collected data. The framework has been validated through the federation of user learning experiences collected from different data sets, but also through the development of two intelligent tools built upon the collected data.

Our works also contributed to increase the quality of the data gathering process. One contribution relied on the design of a goal-oriented methodology providing management systems with self-adaptive features. The methodology is based on the requirements engineering process, and allows monitoring systems to comply with high level quality objectives regarding the gathering process itself. The development of a set of adaptive monitoring patterns that can serve as a reference to guide human administrators to introduce goal-oriented adaptation into monitoring systems, was another contribution. Our approach has been implemented through tools provided by the Distributed Management Task Force, and a case study about the management of a cloud provider for computer education showed how the monitoring patterns can be easily refined to fit the objectives of a specific context.

Design and engineering of engaging TEL processes and systems. Regarding the challenge of efficient education, our research studied how active learning strategies can be used to highly engage students in different forms of learning activities. Specifically, we investigated how social interactions between students and between students and instructors could improve their engagement in active learning activities. Our first contribution addressed the design of a process allowing for instrumentation of Think-Pair-Share strategies as formative assessments in massive learning settings, whether the activity takes place in face-to-face, online or blended settings. This process stands on peer assessment and socio-cognitive conflict to make students develop their critical thinking, and to increase the quality of feedback they are provided with. Our

second contribution relied on a formative assessment system implementing the process we defined, and developed as a web application freely available online. Several experiments of this tool have been conducted in higher education, and results showed that students' level of engagement in massive online formative assessments is inline with the findings of prior research in the context of small classrooms.

Our research also focused on the design of remote laboratories in the context of computer education, to give students the opportunity to deeper develop their professional skills. Our contributions in this field were technical on one hand, and pedagogical on the other hand. On the basis of a network management standard, we adopted a model-driven approach to provide students with their own virtual computing infrastructure according to the practical activities defined by teachers. We also investigated how learning analytics could be used to instrument various forms of collective learning into remote laboratories, and designed new tools to foster learners' awareness and reflection. Our laboratory for computer education, Lab4CE, has been experimented with first year undergraduate students in face-to-face settings. Experimental results suggested a positive effect of the system on learners' engagement in system administration activities. Other findings highlighted a significant positive correlation between learners' level of engagement and their performance at the academic test, but also showed that further research is needed to increase social interactions between learners as well as peer support.

Content of the manuscript

This document is composed of three main chapters presenting and discussing a synthesis of our research work, and emphasising the main contributions and limitations. The last chapter exposes a general report about our activities and gives details about *my* future research plans.

Chapter 1 entitled "Quality development of learning resources and trainings for global education" focuses on the (meta)data models and tools we designed to support development of open educational resources in complex settings. It also presents our competence-based approach to develop engaged learners and sustain lifelong learning.

Chapter 2 entitled "Quality-oriented monitoring of user learning experience" introduces our model-driven framework to represent human-computer interaction data in TEL environments, together with the computational architecture ensuring privacy of stakeholders. This chapter also gives an overview of the goal-oriented methodology we specified to introduce quality in the self-adaptive gathering process of these data.

Chapter 3 entitled "Formative assessment and inquiry-based learning to foster active learning" exposes the new process and tools we developed to bring Think-Pair-Share strategies into massive learning contexts. We also demonstrate how learning analytics can help to design innovative scaffolding tools that can be combined with inquiry learning to support awareness and reflection of learners when they come to acquire professional competences.

Chapter 1

Quality development of learning resources and trainings for global education

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1.1 Introduction

The Organisation for Economic Co-operation and Development (OECD) report on the future of work (UNESCO, 2019) showed that the labour market is moving: between 1995 and 2015, the number of jobs in the manufacturing sector decreased by 20%, whereas it increased by 27% in the service area. This trend shows that efforts and initiatives are needed to meet the growing demand for further and better education worldwide. To face this global challenge, two significant movements emerged in the 2000s: open education, and competence-based learning and training.

According to Blessinger and Bliss, open education "*allows people to continually improve their knowledge and skills throughout the course of their lives*" (2016, p. 26). In their brief history of open education, they emphasise that open education started fifty years ago with the creation of open universities such as the Open University of the United Kingdom. The idea behind open universities was to remove barriers to students willing to pursue education. Also, along with the ubiquity of Internet, a significant movement came out in the early 2000s to foster dissemination of learning content produced by HEIs at a large scale. UNESCO first defined the term "open educational resources" in 2002 at a forum on open courseware, and redefined OER in 2015 as "*any educational resources [...] that are openly available for use by educators and students, without an accompanying need to pay royalties or license fees*" (Butcher, 2015, p. 5). The OER movement rapidly gained great interest and was seen as an opportunity to share educational material at a global level (Caswell et al., 2008). Compared to learning objects, defined by the IEEE Learning Technology Standards Committee as "*any entity, digital or non-digital, that may be used for learning, education or training*" (2002), OERs are characterised by five Rs describing the possibilities offered to users with regard to the openness of OER licenses (Wiley and Hilton III, 2018): retain, reuse, revise, remix and redistribute. In our works, we consider open educational resources as learning objects characterised by a license implementing these five Rs. For instance, we consider digital resources characterised by any license of the Creative Commons¹ as OERs.

Even if the OER movement contributes to meet the growing demand for access to knowledge worldwide, other efforts are required to meet the needs of the labour market at a global level. Indeed, the OECD also emphasises that many adults do not have the right skills for emerging jobs (UNESCO, 2019). Since 2000 and the Treaty of Lisbon making lifelong learning a major contributor to a competitive and dynamic knowledge-based economy in Europe (European Council, 2000), universities and others HEIs started developing competence-based curricula in order to better align skills delivered through educational programmes with those required by the labour market. Competence is a complex concept that has been defined by many researchers. There is no universally accepted definition of this concept, but literature shows that competences often refer to groups of knowledge, skills, abilities and other personal attitudes and experiences (Campion et al., 2011; International Project Management Association, 2015; Kang and Ritzhaupt, 2015). Competences allow students to get engaged in education with a more professional goal in mind (Pérennès, 2013). When adopted in higher education, competence-based approach, also called competence-based learning or teaching, is centred around clear and specific learning outcomes instead of delivering abstract learning.

Global education, when tackled through solutions such as open education or competence-based approach, involves complex processes and concepts as well as a large number of stakeholders. This chapter explains how we did contribute to these two challenges. Specifically, we present different approaches that aim at increasing the quality of the development of both open educational resources and competence-based training programmes. Our research approach focused on two things. On the one hand, on supporting educational stakeholders in developing quality OERs. And, on the other hand, on providing them with technological solutions to help them ensuring that the educational programmes meet their objectives in terms of competences. We aimed at supporting educators in the production of high quality content through the design of dedicated methodologies, models and tools. To reach these two objectives, we: (1) adopted a data-driven approach to investigate how educational metadata and their use help providing stakeholders

¹<https://creativecommons.org/>

with awareness about the OER development process and its use in complex ecosystems, and (2) provided a model-driven approach to study how competences could close the gap between the education and business areas.

1.2 Research context and questions

The different approaches proposed in this chapter have been evaluated with the MIAGE (*Méthodes Informatiques Appliquées à la Gestion des Entreprises*) curriculum, a training programme delivering Information and Communication Technology (ICT) and organisation management skills, even if our research focused on providing generic solutions that could be applied to other contexts.

1.2.1 Open educational resources

For decades, higher education specifies reference frameworks to define learning content of educational programmes that must be mastered by learners at the end of the curriculum. Even if physical resources (i.e. paper content) might still be delivered to learners, many learning contents in HEI are now delivered online as digital resources. Our works studied the development of OERs delivered through technology-based environments. TEL environments deployed in HEIs comprise a set of heterogeneous software, but the most common components include: authoring tools used by authors, multimedia and graphic designers to produce educational resources; repositories resulting from an intensive research from more than three decades to offer an infrastructure to index and retrieve educational material; and platforms for online and blended learning, such as virtual learning environments (VLE), to deliver more or less advanced learning functionalities to stakeholders. Also, previous research as well as real-life experiences show that public and private institutions build their own interdisciplinary teams to design and develop educational content. Production and management of learning resources become less and less driven by a single contributor, instead it turns into a team work where experts, designers, pedagogical engineers and educators have to collaborate and exchange relevant data and information.

Open educational resources and their metadata are thus created and modified by multiple stakeholders with very different skills, within complex technological environments. Thus, a certain number of questions arises over time. In what systems are the OERs used or deployed? What has been performed before, regarding both the content and metadata of the resource? What actions should be taken next? By who, and what are the qualifications required to carry out the actions? Which descriptor(s) should be filled in or updated? etc. Metadata standards dedicated to the description of educational content mainly address interoperability issues between systems. Practice reveals that they are mainly used to share and reuse ready-to-use learning resources, but that they are inappropriate to consider the successive revisions of resources.

Therefore, our objective was to support the various stakeholders in the collaborative production and management of open educational resources over their whole lifecycle. From this objective, we derived the following research questions (see the introduction chapter):

RQ 1: What are the different phases of the OER lifecycle?

RQ 2: What metadata are required to support the OER lifecycle? How to extend the predominant standards so that they integrate these metadata?

RQ 3: Who are the stakeholders involved in the OER development process, and what are they responsible for?

RQ 4: How to support stakeholders throughout the entire OER lifecycle?

We addressed this question by introducing a lifecycle-based methodological approach for OER development, supported by various processes and tools that provide stakeholders with the assistance they need to make the best use of the approach. Our proposals have been developed and experimented in the context of the International E-Mi@ge initiative (IEM), an online educational programme delivering the MIAGE curriculum to distant learners.

1.2.2 Competence-based training programmes

The research community does not agree on a universal definition of the term competence. In the remaining of the document, due to its conciseness and expressiveness, we adopt the definition given by the International Project Management Association (2015, p. 15): "*Individual competence is the application of knowledge, skills and abilities in order to achieve the desired results*". Knowledge refers to what someone knows about a subject or concept (e.g. understanding the concept of object-oriented programming); skills denote specific capabilities to perform a task (e.g. being able to develop a class and to instantiate it); and abilities are the effective knowledges and skills translation and application in a given context (e.g. being able to decompose a complex software development task according to an object-oriented approach).

Since it became a useful instrument for the management of human resources, competence has been widely adopted in companies to design evaluation grids or to provide a portfolio of the company's skills. Competence-based tools currently used by companies represent a solid basis for strategic workforce planning, as they offer the opportunity to address management of competences from a human resource logic by measuring the gap between the competences required by the company and those actually developed. On the other hand, higher education institutions implement CBA to close the gap with the professional sector by explicitly describing their curricula in terms of competences to master.

In both educational and professional contexts, competence-based tools and supports rely on competence models (i.e. set of competences) often defined locally for specific needs, and sometimes specified at national and/or international levels for a more global perspective. Even if standards describing competences of a specific area or discipline emerged, they remain independent from each other. Also, competence models used by HEIs and businesses are strongly heterogeneous. It is thus very difficult for HEIs to adapt to industrial moves or to ensure lifelong learning, and companies can hardly identify the training programmes that best fit their workforce needs.

Therefore, our objective was to propose a consistent competence-based description of training programmes and professions. To achieve this objective, we addressed the following research questions (see the introduction chapter):

RQ 5: What representation of competence should be proposed in order to align the description of both occupations and trainings?

RQ 6: How to make this modelling able to link training programmes to labour market?

RQ 7: How to exploit the whole model to support the different stakeholders with relevant competence-oriented tools?

Our approach to tackle these questions consisted in the design of a unifying model able to represent the various entities involved in competence-based approaches, both in educational and professional sectors. Based on the model, we developed several tools intended to different stakeholders and allowing for better awareness about competence-related tasks and processes.

1.3 Contributions

1.3.1 Metadata for open educational resources

Our works aimed at defining a methodological approach for enhancing the quality of the production, reengineering and management of open educational resources. This section gives our main contributions to address RQ1, RQ2, RQ3 and RQ4, including a lifecycle for open educational resources, the specification and semi-automatic generation of metadata required to support this lifecycle, and a set of technological tools to support stakeholders responsible for applying the proposed approach. This research has been mainly developed during Olivier Catteau's Ph.D. thesis (2008), and led us to participate in the AFNOR (*Association Française de Normalisation*) CN36-GE4 group involved in the design of the French profile of the LOM (Catteau et al., 2006b).

1.3.1.1 Lifecycle for open educational resources

To address the development of OERs in a learning context combining heterogeneous TEL applications with geographically distributed stakeholders, we adopted a lifecycle approach. Various lifecycle models have emerged in industry to develop software and services (Ruparelia, 2010), and this approach has been successfully applied in TEL for learning design purposes (Van Rosmalen et al., 2006; Asensio-Pérez et al., 2017).

The OER lifecycle we designed comprises five main phases matching with the "background" colours of Figure 1.1. During the *production* phase, various contributors put their competences together to produce a ready-to-use OER. An expert committee then validates the resource and authorises its *offering*, so it can be integrated into curricula by teachers. Learners and tutors are then able to use the resource during the *learning* phase and, according to the feedback provided by users, a *reengineering* process may occur to enhance the quality of the OER. Finally, when it becomes obsolete, the resource reaches the *removal* phase. During all these five phases, the evolutions of both the content and the metadata describing the resource are *monitored* to make easier the collaboration between the stakeholders.

To refine the lifecycle at a higher level of resolution, we suggested a detailed OER lifecycle represented by the UML state diagram of Figure 1.1 (Catteau et al., 2006a). At the **Initiation** step, the programme committee members who decided to create a new resource provide metadata about the discipline, objectives, prerequisites and intended end users of the resource. A study about how to achieve the objectives is conducted by domain experts and pedagogical engineers in the **Design** step. Then comes the **Development** step that leads to a concrete and operational resource, thanks to the cooperation of graphic designers, multimedia specialists and ergonomists. The content of

the resource is not modified during the Classification step, instead archivists classify the resource on the basis of standard proposals such as the Dewey decimal classification (Dewey, 2011; Satija, 2013). This process aligns resources with each other according to homogeneous classifications, but also enhances the efficiency of the reuse process. During the Validation step, editorial board members evaluate the quality of the OER regarding both its content and format, as well as its metadata. When revisions are needed, the resource goes back to the design, development or classification step. If it is evaluated as obsolete, the resource reaches the Withdrawal step and becomes unavailable. In case of positive evaluation, the resource enters the Dissemination step and becomes available to users. Pedagogical managers and teachers can thus Search for the resource and integrate it into their learning scenario. Learners and tutors then exploit the resource during the Usage step before providing Feedback. Finally, the resource goes back to the validation step for feedback analysis and identification of optional and/or required adaptations, and the lifecycle starts again from this phase.

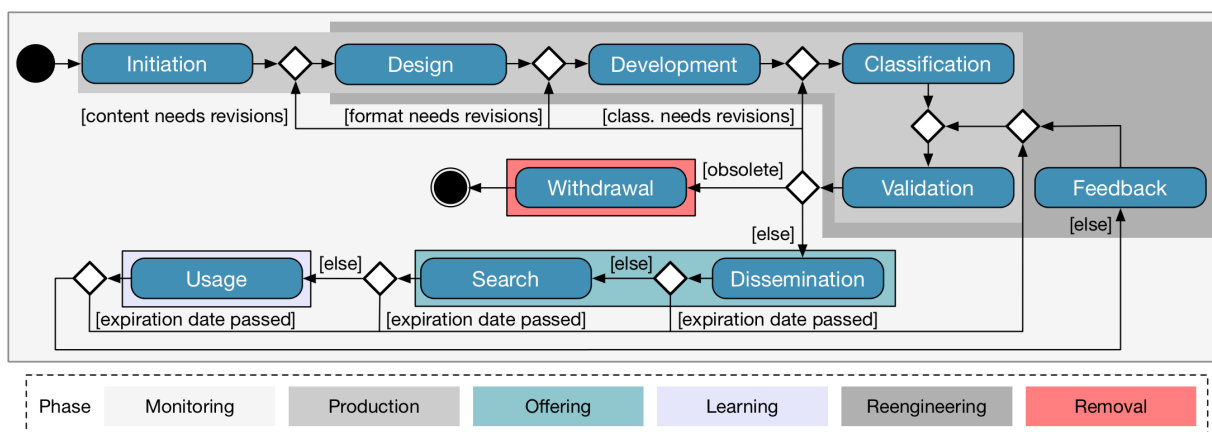


Figure 1.1. Lifecycle of open educational resources.

1.3.1.2 Metadata to support OER lifecycle

The IEEE LOM standard (Learning Technology Standards Committee, 2002) and its application profiles have been and are still the most adopted metadata schema to describe educational resources. As an illustration, the Open Discovery Space portal (Nikolas et al., 2014) adopted this standard to unify the description of near one million resources provided by more than thirty learning objects repositories. Even if the LOM comprises a wide set of descriptors including a category dedicated to learning resources lifecycle, additional metadata and vocabularies had to be specified in order to fully address our lifecycle proposal. The LOM extensions we suggested appear in Figure 1.2 (Catteau et al., 2006c).

The native 2.2.Status descriptor has been reused to specify the various steps of the OER lifecycle. However, as the IEEE vocabulary covers three of the ten stages only, we specified new vocabulary matching with the phases of our lifecycle. Also, the IEEE vocabulary suggested to specify the role of both content and metadata contributors (i.e. 2.3.1.Role and 3.2.1.Role respectively) is too poor. We thus recommended, like the french LOM-FR application profile²,

²<http://www.lom-fr.fr/>

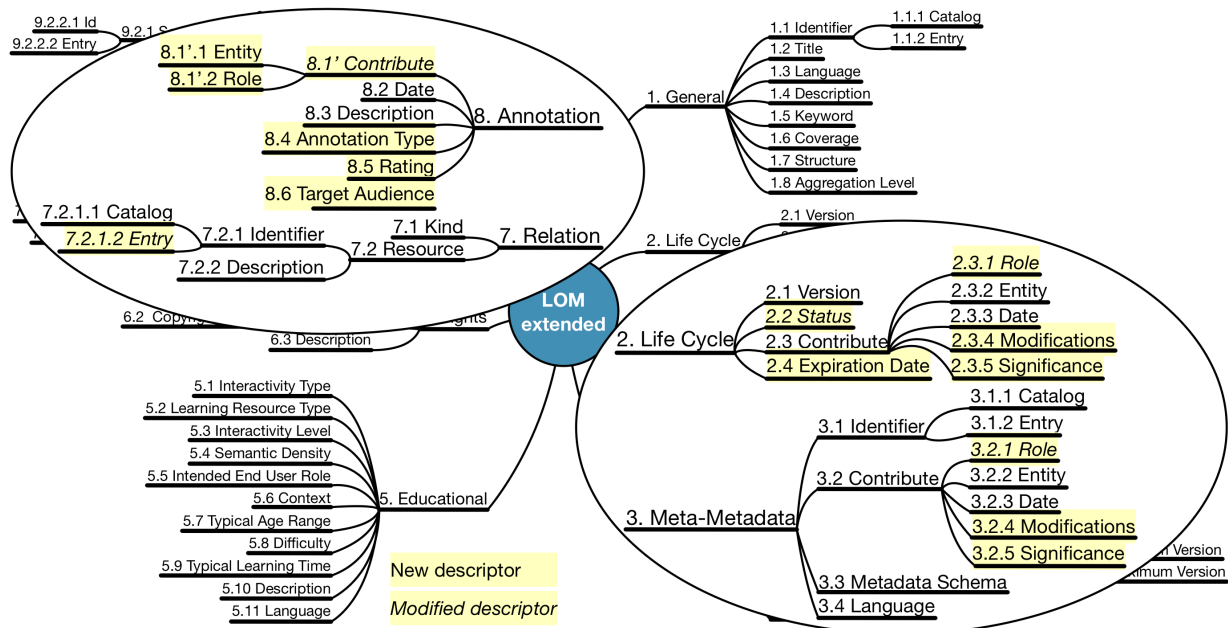


Figure 1.2. LOM extensions to support OER lifecycle.

to use the large set of roles defined by the International Federation of Library Associations and Institutions in the UNIMARC Bibliographic (Hopkinson, 2008). Also, to improve the traceability of a resource, we recommended that the 7.2.1.2.Entry descriptor targets the metadata identifier of the resource it is related to, instead of referring to the resource identifier itself.

Regarding the extensions we defined, the new descriptor 2.4.Expiration Date indicates whether the resource can still be disseminated and used in a curriculum. We introduced another descriptor (i.e. 2.3.4.Modifications) so that each contributor is able to provide textual information about her contributions to the content of the OER. In addition to this qualitative data about content modifications, the metadata 2.3.5.Significance gives quantitative information about the significance of the modifications. We applied the same reasoning to the metadata themselves and specified two other descriptors (i.e. 3.2.4.Modifications and 3.2.5.Significance). These new metadata allow to describe the modifications that have been made between two revisions of the same resource, and facilitate decision-making: programme committee can more efficiently measure projects' advances, or training managers can more easily get interested in integrating the new revision of an OER in their curricula. Finally, to enhance accuracy of the native 8.Annotation category for gathering feedback, we defined (i) an extension of the contribution descriptor (i.e. 8.1'.1.Entity and 8.1'.2.Role) to express both an entity and role; (ii) the new metadata 8.4.Annotation Type that provides information about the granularity of the annotation; (iii) the new descriptor 8.5.Rating that allows users to assess the quality of the resource; and (iv) the element 8.6.Target Audience that specifies the stakeholder(s) the annotation is intended to.

1.3.1.3 Generation of metadata

The extended metadata schema we built takes into consideration the whole OER lifecycle proposal. However, in return, it increases the workload of the stakeholders involved in the OER

development. We investigated three different methods facilitating this skills- and time-consuming process that can be mixed together to assist users in metadata generation.

Role-based and progressive generation of metadata. The indexation process often occurs when the learning object is finalised and ready to use. As a consequence, the big number of metadata is filled out by a single person who might not have all the required competences. Prior research has suggested to distribute the indexation process to several contributors with complementary skills (de La Passardière and Jarraud, 2005; Rebaï and Labat, 2006). Our approach goes further by considering that indexation must be addressed by several contributors, but must also occur at each phase of the lifecycle, as soon as the initiation step is launched (Catteau et al., 2007c). A role-based and progressive metadata generation increases the quality of the metadata, as each stakeholder fills only the metadata she is responsible for and according to her role.

The role-based and progressive generation of metadata we suggested is exposed in Figure 1.3. Since the main goal of the initiation step is to define the objectives of the resource, the task of the programme committee members mainly consists in setting general and educational metadata. During the design phase, designers define the description and structure of the learning resource, the remaining educational metadata and the possible relations. If a feedback phase has occurred, they also modify the version of the resource. Authors then provide details about technical metadata and relations of the resource with other material; like designers, they might have to modify the version after feedback has been given by users. Librarian are responsible for the classification of the resource. In the validation phase, the editorial board sets the expiration date of the OER. Also, when a feedback phase has occurred, they might have to validate the comments given by learners and tutors. Finally, several metadata have to be modified at each stage of the lifecycle. These descriptors include the state of the resource, the contributions of each stakeholder, and the relation with the previous revision if the resource is not being initialised.

Using these recommendations, metadata are filled out step-by-step from the initialisation to the validation stages by appropriate contributors, and the number of descriptors under the responsibility of a given user significantly decreases. However, a mechanism is required to spread and aggregate the metadata specified by each contributor in order to build a full metadata record.

Propagation of metadata. Most of metadata describing an OER can be reused from one stage of the lifecycle to the next one, or between two revisions of the same resource within a single stage, but some of them have to be specified again in case of specific circumstances. Metadata that can not be reused from one phase to another are detailed in (Catteau et al., 2007c). They relate to the metadata identifier which changes at each stage, to the status of the resource, or to technical details about the resource. For instance, as two successive revisions of the same resource in the development stage are often characterised by different size and duration, those metadata have to be specified again. Another example is the metadata of the *Annotation* category which are used after the feedback phase to re-engineer the content of a resource, and that do not apply to the new ongoing version of the resource.

Automatic metadata generation. Automatic mechanisms can be used to make the indexation process easier for contributors. Authoring tools often include general and technical metadata that can be automatically extracted from the resource at the time it is indexed into the repository (Cardinaels et al., 2005). However, as authoring tools are not dedicated to education, one challenge is to discover and/or compute educational metadata. Some solutions based on natural language processing algorithms have been proposed to reveal the language of a learning

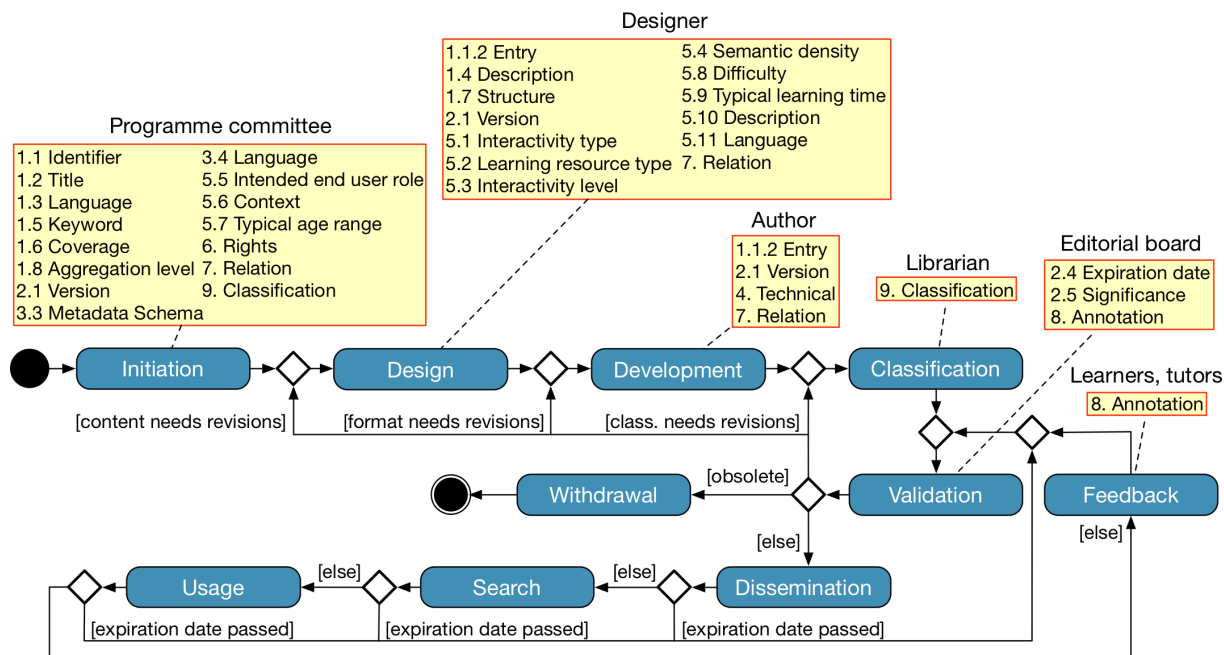


Figure 1.3. Role-based and progressive metadata generation.

object or its classification (García-Floriano et al., 2017), while others gather information from a set of tools to infer metadata (Lehmann et al., 2007). In (Broisin et al., 2005), we demonstrated how the learning context in which a resource is used can lead to automatic semantics and educational metadata generation. For instance, when a resource is indexed from a virtual learning environment, the description, target audience, disciplines or intended end user role can be inferred from the VLE itself. Combined with algorithms extracting information from the digital file, the framework we designed in the context of the ARIADNE foundation allowed for automatic generation of seventeen mandatory metadata out of the eighteen required fields of the application profile, thus significantly decreasing the workload of metadata contributors.

1.3.1.4 Visualisation of metadata

The collaborative production and management of educational content make it very difficult for the collaborators to build a true and fair mental representation of the resource model and of its successive evolutions. We suggested two different visualisations to provide stakeholders with awareness about the OER development process.

The 3D visualisation tool. To ease the visualisation of the various evolutions and revisions of a given resource, we designed a data visualisation tool exploiting the *Relation* category and vocabulary of the LOM. Our visualisation model adopts three dimensions to represent the different types of relationship that may be established between educational resources.

The details of the tool illustrated in Figure 1.4 can be found in (Catteau et al., 2007a). Basically, the temporal axis is used to highlight the successive revisions of a resource. The objective axis represents relations between resources that target different objectives. This axis is not restricted to the pedagogical perspective, it also refers to interactivity objectives, economic

objectives, etc. The third axis takes into account the granularity level of educational resources. For instance, Figure 1.4 shows a resource A1 composed of two resources R and M characterised by a smaller granularity level. This axis can also be used for requirement or reference purposes.

In addition, in order to make users able to easily visualise the status of a resource within its lifecycle, we associated a colour schema with each stage of the lifecycle. The dark green colour (i.e. *Ready-to-use*) applies to the dissemination, search and usage steps, as the resource has been previously validated for offering.

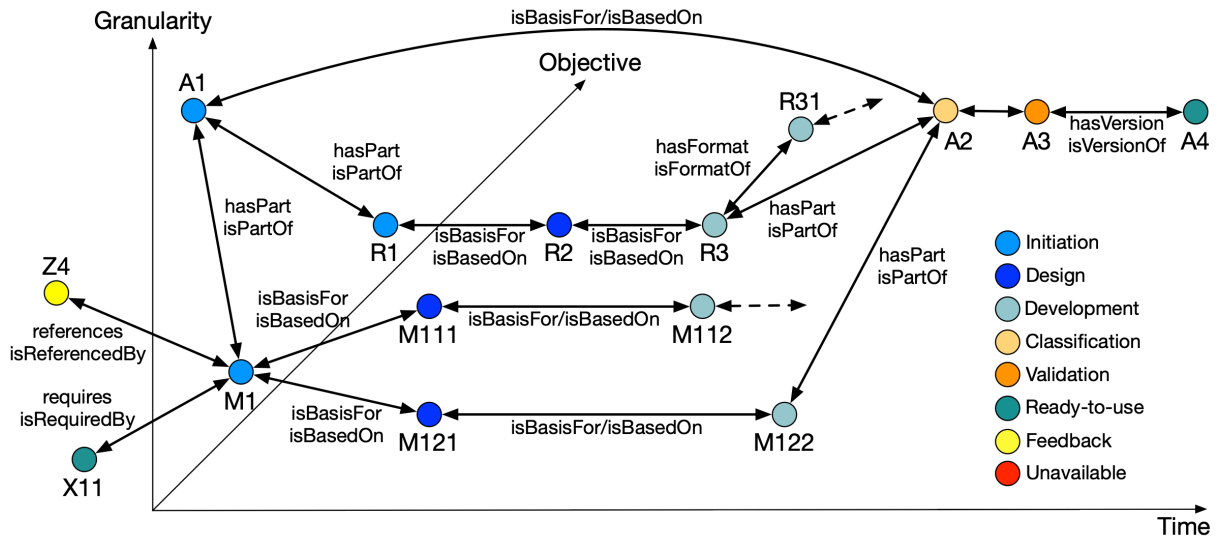


Figure 1.4. 3D visualisation of educational resources evolutions and relations.

Treemap representation. Our approach considered that OERs are stored all along their lifecycle into a dedicated repository for share and reuse purposes, and exploited within virtual learning environments to support users with educational features around the resources. The aim of the visualisation presented here was to provide awareness about the divergences between the resources integrated into a VLE, and their evolutions stored into the repository (Catteau et al., 2008a). This tool aimed to help teachers to keep their courses up-to-date during the Usage phase and to anticipate the adaptations that might be needed according to the upcoming new release of a resource, or managers to make decisions about the re-engineering process.

Virtual learning environments often adopt a hierarchical model to organise courses. Node and link tree diagrams might be used to visualise such data structures, as shown in Figure 1.5a. However, this representation model becomes inappropriate in case of large hierarchical data sets. To ensure scalability, the treemap approach, a space-filling method, has been developed by Johnson and Shneiderman (1991). The simplest form of this approach exposes a 2D diagram where only the leaves of node-link diagrams are represented. In addition, the state treemap representation enhances 2D diagrams by offering the opportunity to visualise the status of the data according to a predefined colour schema associated with a given semantics (Molli et al., 2001).

Before designing our visualisation, we first identified the main points of divergence between resources stored into a repository (the remote resources) and their instantiations deployed within VLEs (the local resources). Table 1.1 details the situations we addressed, and specifies the matching status and colour schema of the local resource. Let us note that this status is not

related to the lifecycle of the local resource, instead it reveals information about its consistency regarding the remote resource.

Table 1.1. Status and colour schema for awareness of divergences.

Status	Colour	Semantics
New release available	Red	At least one release of the remote resource is available for use in the repository
New competitive resource available	Yellow	At least one competitive resource (in terms of format, interactivity, cost, etc.) is available for use in the repository
Dependency divergence	Orange	At least one revision of a resource required/referenced by the local resource is available for use in the repository
Obsolete	Grey	The remote resource has reached the last step of its lifecycle
Up-to-date	Green	The local resource matches with the last evolution of the remote resource
Re-engineering in progress	Purple	At least one revision of the remote resource is being produced and not validated yet

Figure 1.5b illustrates the state treemap matching with the node and link diagram of Figure 1.5a. In this example, a teacher is responsible for three different courses organised in two distinct sub-categories and comprising a total number of thirteen resources. At a glance, our visualisation provides the teacher with global and up-to-date awareness about the status of the whole set of resources she manages, and allows her to take the actions required to reduce the number of divergences. According to this state treemap, the teacher should: update R6; check the ongoing versions of R10 and R12, as well as the competitive resource of R1; find an alternative to R9; use the 3D visualisation tool to identify which dependencies of R3 and R7 have been released. Behind the scene, our tool sends requests to the repository to browse the metadata of the remote resource and check its evolutions. For instance, if the remote resource has at least one *isBasisFor/isBasedOn* or *hasFormat/isFormatOf* relation, and if the status of the target resource is not *ready-to-use*, then the state of the local resource is set to *re-engineering in progress*.

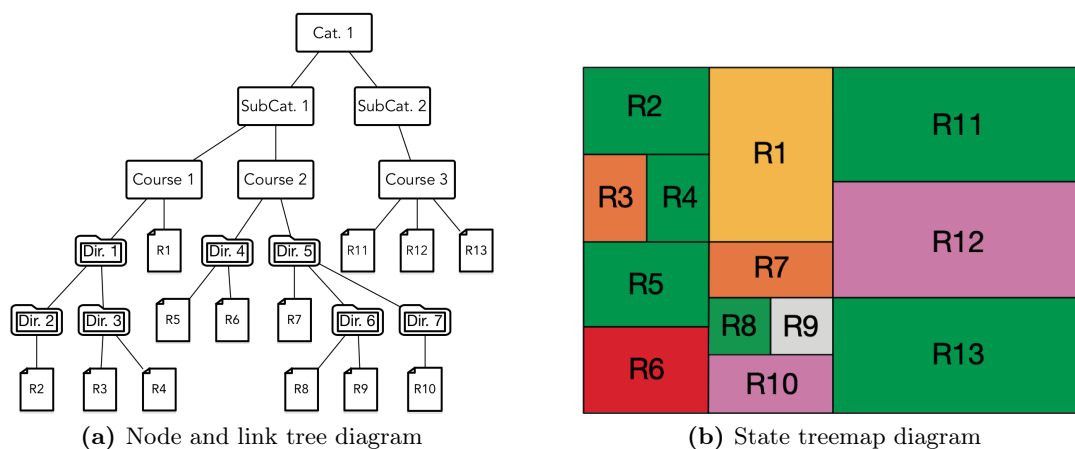


Figure 1.5. Examples of tree diagram visualisation.

1.3.1.5 Experiment with International E-Mi@ge

Our contributions have been experimented with the digital campus International E-Mi@ge (Cochard and Marquié, 2004). This initiative offers lifelong learning opportunities and allows foreign students to remotely obtain the MIAAGE degree. The consortium comprises twenty two French universities, or training centres, and foreign partner HEIs, or relay centres. Within the IEM digital campus, learning resources are produced collaboratively by stakeholders under a Creative Commons license, and then deployed within the VLE of each training centre (Broisin et al., 2006; Catteau et al., 2007b).

A memorandum of understanding has been established between the IEM consortium and the ARIADNE foundation. We thus modified both the ARIADNE metadata schema and the matching repository, according to our proposals. The IEM application profile includes the ARIADNE application profile, extended by the metadata specified in Section 1.3.1.2. Also, the search and indexation tool has been enhanced with extra features: support of the roles defined in the IEM context; an adaptive indexation interface exposing to users, according to their role, only the metadata they are responsible for; an implementation of the metadata propagation process; links to the 3D visualisation. In addition, the state treemap and a widget providing users with a simple interface to give feedback about a resource, have been implemented for Moodle (Catteau et al., 2008b, 2009).

For timing reasons (the development process was delayed and the tools were not released when the production of the resources was launched), but also because of the complex experimental settings, our approach has been experimented with only two courses of the IEM programme. The production of these courses involved three different collaborators from the Paul Sabatier university who informally exchanged information about the progress of the production process. The experimental results allowed us to highlight some improvements regarding the visualisations and tools: a feature to filter data in the 3D tool according to the type of relation or to a specific period of time, as users reported that the visualisation was difficult to use when the number of relations becomes too high; a system to display the modifications and their importance within the state treemap, in order to provide details about divergences.

We planed another experiment in the context of the recent OpenMIAAGE project³, but the production of the learning content has been sub-contracted to a private company, thus preventing further testing and feedback about the solutions we proposed.

1.3.1.6 Discussion and positioning of the works

Lifecycle of educational resources has been in the focus of the research community for a long time. Most of works on this topic, including first investigations (Pernin, 2005; Rensing et al., 2005; Cardinaels, 2007) and more recent studies (Santos et al., 2014; Dix and Leavesley, 2015; Hodgkinson-Williams et al., 2017), propose high-level lifecycle models suitable for simple educational contexts, but inappropriate to ensure quality production and management of OER in complex settings. Our model adopts a low level of granularity to specify fine-grained tasks that must be achieved, from the initiation of an OER to its removal. For instance, whereas various proposals suggest an adaptation or repurpose phase, our approach considers that the re-engineering

³<http://openmiage.univ-lyon1.fr/>

process involves design, and/or development, and/or classification of resources. As a wide range of different skills is required to complete the tasks associated with fine-grained steps, low-level models are suitable to spread the workload among the different stakeholders according to their role and expertise. The closest works to our model are those from [Camilleri et al. \(2014\)](#), inspired by the proposal of [van Assche and Vuorikari \(2006\)](#). However, unlike these initiatives which explicitly include a **publish** phase to make resources available world-wide, we consider that OERs must be indexed into a repository during their entire lifecycle, as soon as the initiation phase is launched, to increase awareness of their progress and of their successive revisions.

To our knowledge, none of the existing works on OER lifecycle provides recommendation about the stakeholders responsible for filling in the metadata. Description or classification of OER often appears as an explicit phase in lifecycle models, and is assigned to a single contributor even if literature strengthened that this process is time-consuming, complex and skill-demanding ([Manouselis et al., 2009](#); [Araújo et al., 2016](#)). Research has thus explored a number of mechanisms and techniques to automatically generate metadata ([Edvardsen et al., 2009](#); [Liu, 2013](#); [Pal et al., 2019](#)). Our model does not include such a description step, as we considered that metadata must be provided step by step by the contributor who has the most appropriate skills. Our approach adopted a role-based and progressive generation of metadata where each stakeholder knows exactly the set of metadata she has to provide. The description process thus becomes a collaborative task supposed to increase the quality of metadata, since each contributor is responsible for a limited number of metadata only. We reused automatic metadata generation techniques to produce technical and content-related metadata, but gave experts the responsibility for providing educational metadata, as literature shown that human-generated metadata are of better quality than those automatically generated ([Pal, 2016](#)). Also, we specified new metadata to make explicit the modifications of both the content and/or metadata of an OER between two phases of the lifecycle. This information makes the description of resources more complete, helps to keep track of the evolutions of OERs, and facilitates decision-making processes.

Research on exploitation of OER and metadata mainly focuses on how to enhance search, reuse and sharing processes. Tools developed around OER repositories are mainly designed to propose innovative visual-based browsing methods ([Klerkx et al., 2014](#); [Gaona-García et al., 2018](#)), or to provide various statistical data about the resources ([Megalou and Kaklamanis, 2014](#)). Other prior works established frameworks for quality of repositories. [Atenas and Havemann \(2013\)](#) identified four categories (namely search, share, reuse, collaborate) and a set of ten "indicators of quality assurance" matching with features that should be supported by a repository. Social features allowing users to review, comment and rate an OER are recommended, even if we think that repositories are not the best place for gathering feedback. Also, none of the quality indicators tackles awareness about relations between resources, or about their evolutions.

When looking at authoring practices, works have proposed requirements about the features that should be implemented by OER authoring tools in global settings. [Nurhas et al. \(2016\)](#) identified key capabilities such as collaborative and concurrent edition of a resource or support for multilingual interfaces, but also highlighted other features for adding a revision or version of a resource. These authors do not provide functional requirements on how to make use of OERs' revisions and versions, but our 3D visualisation might be used for that purpose while offering a new way of browsing a repository. However, due to the difficulty of setting up experiments in authentic global settings, there is still a need for complete evaluation of our proposals.

1.3.2 Model-driven approach for competence-based learning

The works presented in this section aimed at aligning educational programmes delivered by HEIs with professional contexts, using competences as the means for alignment. This research has been conducted in the context of the COMPETENCES project funded by Agence Nationale de la Recherche (ANR) from 2010 to 2014. Our main contributions to tackle RQ5, RQ6 and RQ7 are exposed hereafter, and include a competence-centred unifying model and a set of scaffolding tools intended to facilitate the design of competence-driven training programmes, and to increase awareness about learners' development of competences.

1.3.2.1 Unifying model

The model we designed aimed at reaching varied objectives and targeted different stakeholders: programme committees had to be able to design competence-driven curriculum from a conceptual perspective (i.e. in terms of general learning goals and instructional units) and according to the professions targeted by the curriculum; teachers had to be able to achieve the matching learning objectives through the design of units of learning; learners had to be able to select their courses according to their profile and professional goals and expectations, but also to self-position within their learning paths. The following requirements have thus driven the design of the model:

1. Decomposition of competence in terms of knowledge, skill and attitude (KSA): it allows to define competence at a low granularity level, and to comply with most approaches of literature;
2. Competence responsibility level: for each KSA element composing a competence, it represents the level of responsibility required by a profession, or achieved through a training programme;
3. Competences as learning objectives: the objectives to reach by means of a combination of units of learning;
4. Frameworks of competences: they represent aggregations of competences developed in a curriculum, or required for a given profession.
5. Conceptual representation of educational programmes: it allows to describe learning goals and objectives without detailing the matching pedagogical strategies;
6. Organisational representation of educational programmes: it describes the learning designs allowing to reach the learning goals and objectives;
7. Classification of professions: it allows to group professions together according to their industrial area;
8. Learner profile: this supports past/current professional/educational experiences of learners;
9. Support for outstanding standards: it ensures integration of existing initiatives;
10. Balance between generality and pedagogic expressiveness: it ensures that the model can be implemented and used by both human and computers.

The UML diagram of Figure 1.6 illustrates a simplified representation of our global model unifying training programmes, professions and users around competences. The detailed model

can be found in (Venant et al., 2015b). Competence is modelled by the khaki green classes. According to the definition adopted in Section 1.2.2, it is described in terms of knowledge, skills and attitudes, and associated to levels of responsibility. This last information has a different meaning than the Bloom proficiency level (Silva, 2009), and is defined by the European Qualifications Framework (EQF) as *"the ability of the learner to apply knowledge and skills autonomously and with responsibility"* (European Commission, 2008). The concept of framework makes it possible to put together different competences, and thus to take into account frameworks of reference.

Educational trainings delivered by HEIs appear in the right part of Figure 1.6, and distinguish between curricula and their instances. A curriculum is defined as a set of learning goals providing the general intention of what is learnt in the curriculum, and is associated to one or several levels (e.g. bachelor, master). Instructional units allow to reach the learning goals, and are described in terms of learning objectives to specify more specific expected results about what participants should learn with the curriculum. Learning objectives are expressed as KSAs, thus allowing for identification of the competences delivered by a curriculum. On the other hand, a training programme represents an instantiation of a curriculum, and is defined as a set of learning units (in the sense of the IMS Learning Design standard) composed of varied learning artefacts (e.g. courses, exercises, projects, activities). Units of learning are associated to learning objectives to make sure that they cover all the objectives of the instructional units, and facilitate the process of designing the matching learning artefacts. This modelling approach follows one of the best practices in competence modelling suggested by Campion et al. (2011) and consisting in linking competence models with learning goals and objectives. It provides the opportunity of defining learning goals and objectives that will be shared among several educational institutions, which are then free to design their own units of learning to reach these learning goals and objectives.

The top part of Figure 1.6 represents professions. Associations between professions, profession families and industries offer a fine industrial classification of jobs, and are especially useful to facilitate learner's learning path as it is possible to identify professions matching with her career plan. A profession is described in terms of responsibility levels of each competence required by the profession. Like competences, professions can be grouped together into a framework to facilitate integration of well-established initiatives describing professions of a given industrial area.

The learner model illustrated by the orange classes in Figure 1.6 focuses on the cognitive profile and preferences of learners. The cognitive profile is linked to one or more professions to reflect the past/current professional experiences of a learner, and to the certifications the learner obtained. The different KSAs developed by a learner in other than professional or training contexts, are also considered. Preferences are addressed in terms of professions and competences to depict the expected career plan.

1.3.2.2 Competence-based scaffolding tools

On the basis of this model, we developed a set of tools integrated into a web platform⁴, and introduced different reference frameworks related to Information and Communications Technology (see Section 1.3.2.3). Here, we present the main tools of the platform.

Design of curriculum. The process of designing competence-based curricula must ensure that the learning goals and objectives of a curriculum cover the competences required by the jobs

⁴<http://miage-competences.francecentral.cloudapp.azure.com/#/>

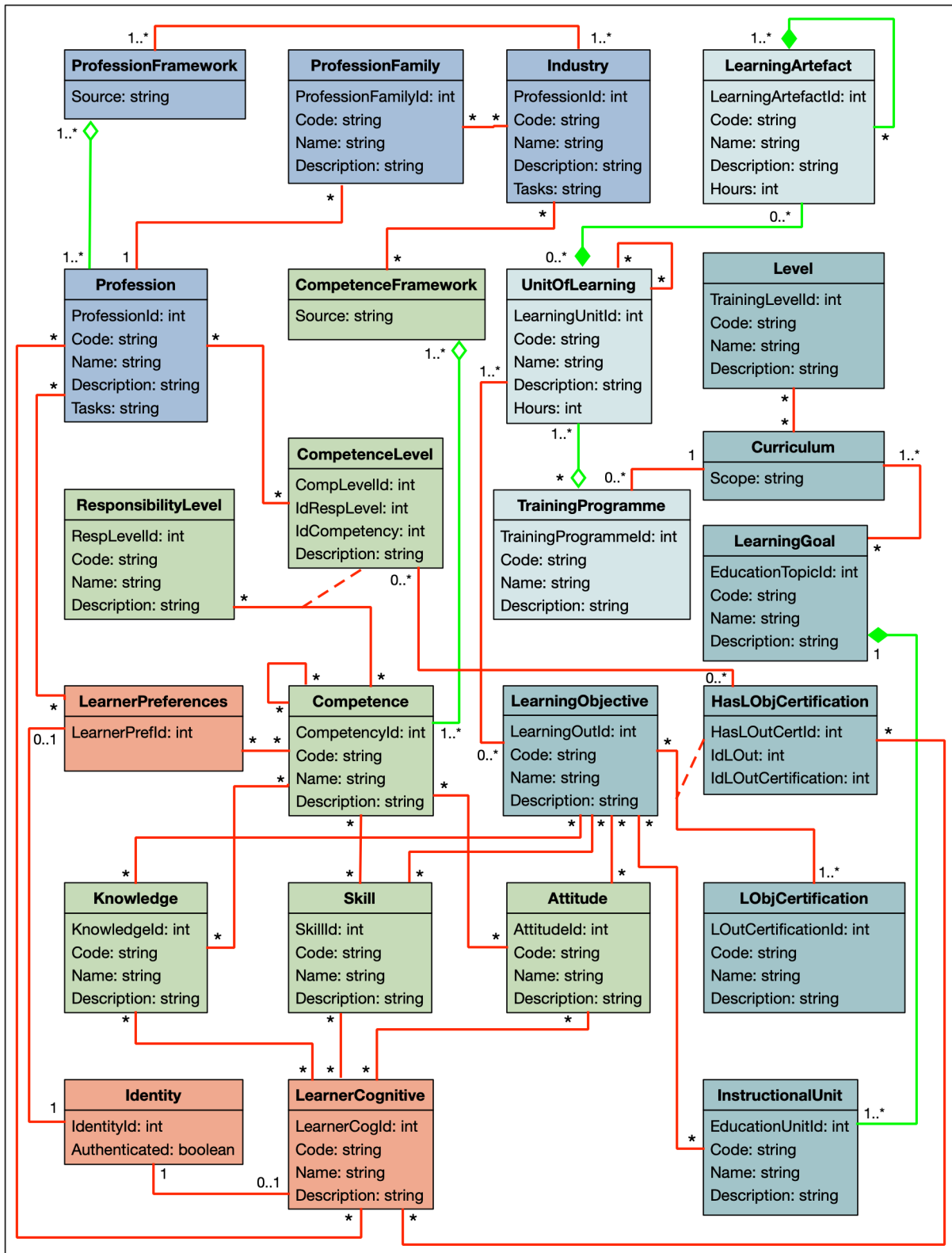


Figure 1.6. Competence-based unifying model.

it addresses. The tool we designed is intended for programme committees and training managers, and aims to support the design of new curricula and training programmes. Literature showed that in higher education, curricula used to be designed according to initiatives developed by a single researcher or a small group of individuals (Beckmeier and Neusel, 1991), thus leading to a disciplinary-oriented regulation of curricula following a supply logic (Mignot-Gérard and Musselin, 2001). Instead, our approach adopts a demand logic and promotes strong relationships between competences expected by the work sphere and those addressed by a curriculum.

The assistant tool supports both the conceptual design of curriculum and the organisational structure of the matching training programme(s). Conceptual design comprises three main steps. The outcome of the first step is a set of competences, inferred by the tool on the basis of the professions targeted by the curriculum and specified by the programme committee. The outcome of the second step is the set of learning objectives that have to be reached through the curriculum, derived from the learning goals and instructional units. The tool is then able to check that the learning objectives cover the whole set of knowledge, skills and attitudes associated with the competences addressed by the curriculum. The graphical user interface notifies the user if one or several competences are not taken into account. This notification process contributes to increase quality of the design process regarding consistency between target competences of the curriculum and those actually delivered through the instructional units. Regarding the organisational design of training programmes, training managers define the units of learning in terms of title, description, number of hours and semester, and they also bind each unit of learning to one or more learning objectives of the curriculum. When all units of learning are specified, the tool makes sure that at least one unit of learning is associated with each learning objective, and notifies the user if a deficiency is detected. Thus, after the organisational design is completed, the tool ensures that the units of learning of the training programme cover the target competences of the curriculum. At this point, the design and development of learning artefacts comprised in each learning unit can be launched, but this process is out of the scope of the tool.

The tool also offers the opportunity to generate a plain text document matching with the syllabus of a programme. This document comprises the organisational structure of the programme (i.e. the various learning units and their details), the competences it covers, as well as the professions the graduated students could apply to. A graphical representation of these data has also been built to expose the links between the various entities. In Figure 1.7a (respectively 1.7c), the mouse is over one specific learning unit (respectively one occupation) and the tool emphasizes the competences it addresses (respectively requires). When the mouse is over a competence, the matching learning units and occupations are highlighted (see Figure 1.7b).

Recommendation of training programmes. The growing offer of training programmes makes it very difficult for learners to get an overview of the high number of training opportunities. In 2017, twenty three different professional bachelor degrees and twenty three different master degrees related to the digital area were delivered by public French institutions, excluding the larger and larger portfolio of private engineering schools (France Stratégie, 2017). This report claims that even the French ministry of higher education is not able to establish an exhaustive list of the existing training programmes in this area. Although training managers engage more and more resources in the description of their curricula, it remains very difficult for learners to select the programme that best suits their professional expectations. We thus designed a tool that aims at recommending training programmes to learners according to their past training and/or working experiences, and to their future professional objectives.

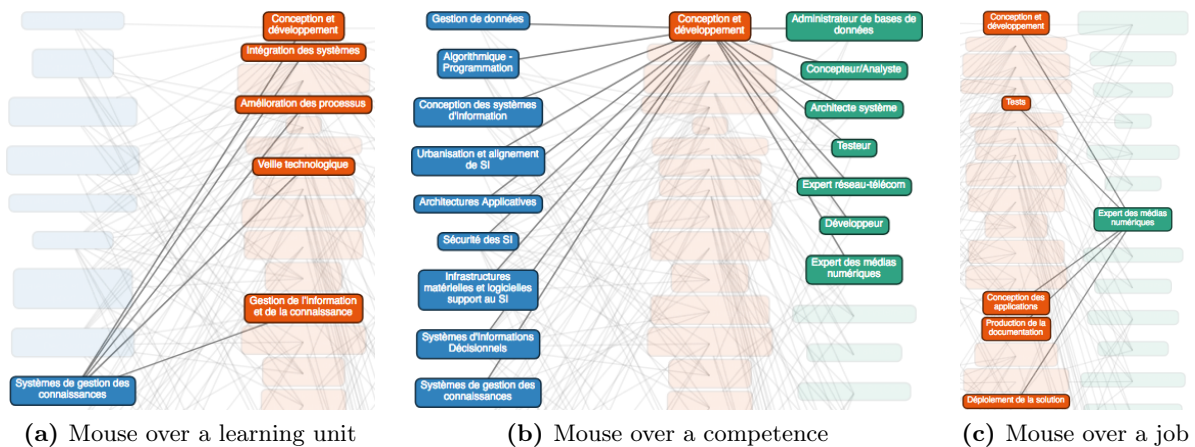


Figure 1.7. Links between learning units, competences, and professions.

Our recommendation process comprises the following steps: completion of the learner profile in terms of competences and professional expectations; identification of the competences required by each occupation specified in the learner profile; comparison between learners' and jobs' competences to spot those that the learner has to acquire; identification and recommendation of the training programmes that best cover the competences identified in the previous step. To accomplish the first step, the tool asks the user for her professional objectives, and then invites her to give her past professional experiences together with the competences she mastered in other contexts. Other steps are automatically processed by browsing the data model. The outcome of the recommendation process is a list of training programmes containing, for each of them, the following information: (i) the competences to acquire and that are addressed by the programme; (ii) the competences to acquire and that are not addressed by the programme; (iii) the learner's competences that are also addressed by the programme; (iv) the other competences addressed by the programme. Also, a pie chart allows to easily visualise the coverage rate of the programme regarding the new competences to develop.

Awareness of competences development. When learners follow a learning path, a motivational practice consists in helping them becoming aware of their development in regards to their personal objectives (Husman and Lens, 1999). In a competence-based programme, one way to provide such awareness is to allow learners to self-position in each unit of learning, and to expose their level of responsibility regarding the competences addressed by the programme.

To provide learners with a synthetic view of their progress within the training programme, we designed a visualisation tool illustrated in Figure 1.8. The training programme is structured according to the learning units it provides, represented as temporally-situated nodes, and leads to the expected jobs of the learner. Based on the learner's assessments results, the tool infers an indicator allowing learners to be aware of their weakness, proper mastering or absence of assessment regarding each learning unit; these status are respectively represented as red, green and orange nodes on the graph. Paths from one node to another illustrate the competences addressed by each learning unit. In order to allow visual representation of the learner's level of responsibility regarding these competences, we adopted a force-directed layout between nodes: the less a learner masters a learning unit, the thicker is the competence path. A sorted list of the

competences is also generated below the graph, where those requiring a greater attention from the learner appear on top of the list. This dynamic visualisation allows learners to get aware of their achievement and progress regarding their professional expectations.

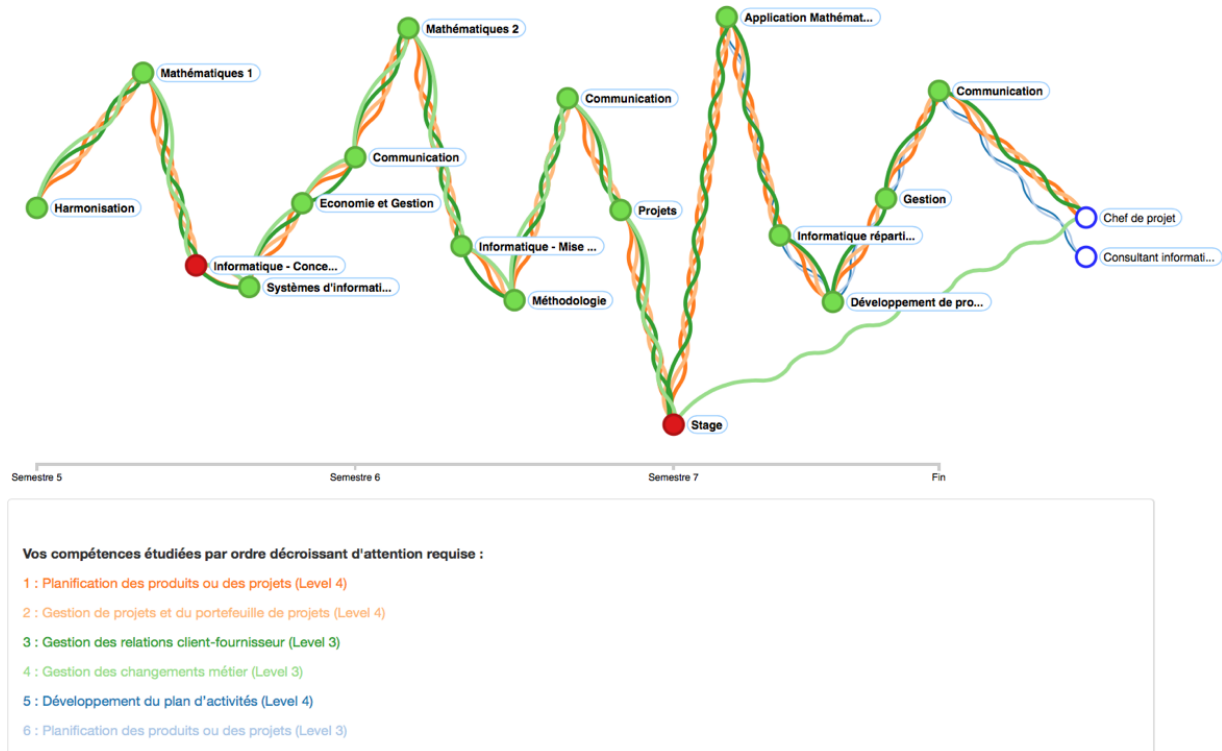


Figure 1.8. Awareness of competences development all along a training programme.

1.3.2.3 Validation with standard initiatives

To validate our approach, we instantiated the data model of Figure 1.6 with varied existing standards referencing competences, training programmes and professions (Venant et al., 2015a). These works have been conducted in the scope of the COMPETENCES project, whose aim was to set up a quality-oriented approach for re-engineering of learning resources and trainings to promote development of learners' competences. Since the Paul Sabatier partner was, and is still strongly engaged in the MIAGE curriculum, it has been the subject of our experiments. This curriculum trains specialists in management of information system, and defines a common set of competences in ICT, management, and professional methods. Each university delivering the MIAGE degree is free to adapt the curriculum to its local expertise. For example, the programme delivered at Paul Sabatier has a strong emphasis on distributed systems and network management, whereas the programme delivered at Lyon 1 puts a strong focus on organisational management. In total, twenty different programmes are delivered by twenty different universities, but all students earn the single MIAGE degree. This curriculum, together with the twenty programmes, have been indexed into our repository using the design tool. Indexation of these entities helped us to identify and solve minor modelling issues, and the design tool is now free of bugs and used to generate the syllabus of the different programmes when needed.

Regarding competences, a number of initiatives specific to different domains has emerged for the past ten years. In the ICT area, the version 3.0 of the European e-Competence Framework (e-CF) became a standard in 2016 and was published officially as the norm EN 16234-1 (European Committee for Standardization, 2014). It describes forty ICT competences to promote lifelong learning and learners' and workers' mobility. At a national scale, the Certificate in Internet and Information Systems for Engineering (C2i2mi) is a French certification delivered by HEIs to vouch for the mastery of professional working methods related to information systems and project management (Ministère de l'Éducation Nationale, de l'Enseignement Supérieur et de la Recherche, 2015). Both frameworks summarise competences as a title, and the e-CF includes additional metadata such as a textual description and a non exhaustive list of knowledge and skills. Also, the e-CF outlines each competence in several levels of responsibility. e-CF and C2i2mi have been implanted in our repository of competences. Figure 1.9 illustrates the mapping between the e-CF and our model, where associations are blinded for readability reasons.

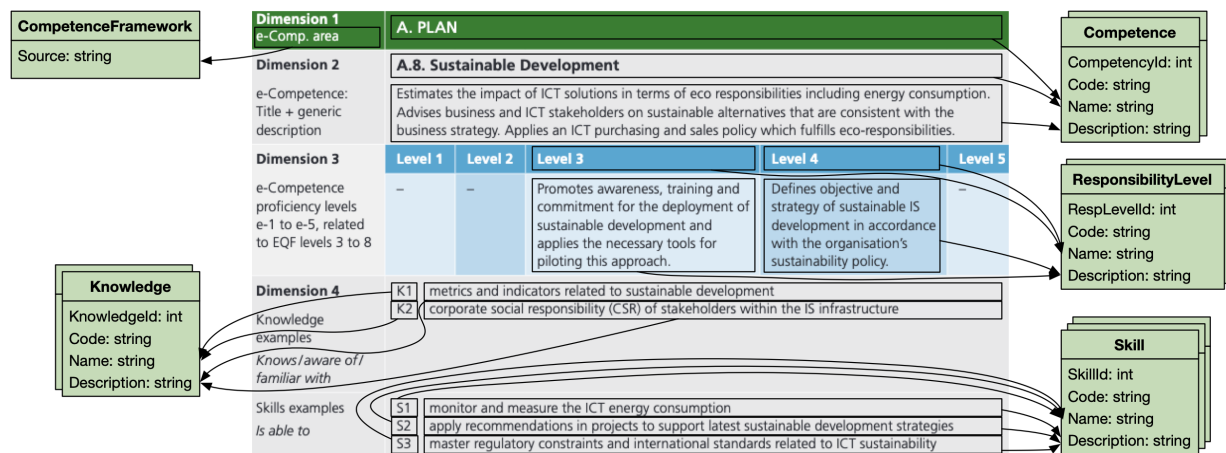


Figure 1.9. Mapping from e-CF to our model.

In the professional sector, several initiatives emerged to describe occupations as a set of required competences classified within groups, or families. In the ICT area, two reference documents have been built: the European ICT Professional Profiles (European Committee for Standardization, 2012) and the Human Resource nomenclature specified by the CIGREF (CIGREF, 2011). Both specifications propose the same metadata to describe job profiles, including a title, a summary statement, a detailed mission and a list of tasks. More interestingly, they also both stand on the e-CF to depict these profiles in terms of competences and levels of responsibility. We populated the profession model with these two specifications, and defined the large number of associations between these job profiles and the e-CF competences.

1.3.2.4 Discussion and positioning of the works

Interest for modelling of competences started in the 2000s with international standards such as IMS Reusable Definition of Competency or Educational Objective (IMS, 2002), or IEEE Reusable Competency Definitions (IEEE, 2006). These standards focused on interoperability between competence-based systems, and provided common definitions intended to facilitate sharing and reuse of competences. Projects such as TENCompetence (Koper and Specht, 2007) or

Explor@ (Paquette, 2007) extended these standards to support responsibility level or assessment of competences (Sampson and Fytros, 2008), but this research did not address the issue of how competences are to be integrated in systems targeting wider and more complex processes than competence representation and exchange.

As organisations showed a growing interest in competences, prior works on competence-based approaches investigated how to develop innovative business and human resource management solutions (Liquid Technologies, 2007). They provided models and tools to increase quality of business processes (Capuano et al., 2011), foster management of enterprise competences (Barbosa et al., 2015) and knowledge (Kieslinger et al., 2009; Jovanovic et al., 2011), or measure mastery level of competences (Põldoja et al., 2014). As shown in Table 1.2, these works hardly fit with our requirements because they mainly focus on the professional perspective. Other research and projects studied competence-based adaptive learning or design of training programmes, but they lack details in competence representation (Rezgui and Mhiri, 2019) or include learning activities only, without considering training programmes (Karetsos and Haralambopoulos, 2011). The ARISTOTELE (Del Nostro et al., 2013) and SIRET (Miranda et al., 2017) projects defined a competence model inline with our proposal. Their ontology-based approach also stands on main classes representing competence (as knowledge, skill and attitude), training programme, profession and learner. Since their objectives is to support competence-based adaptive and personalised learning, these models go further in terms of competence assessment to facilitate automatic selection of appropriate units of learning. The weaknesses of these works rely on the conceptual description of curriculum which is not taken into account, as well as on the complexity of the ontologies that might require a significant experience to fully exploit the model.

Table 1.2. Alignments of competence-based approaches with our requirements.

Requirements	Competence-based approaches							
	HR-oriented			Learning-oriented				
	ARIST.	De Com	HR XML	Karet.	Intel-LEO	Digi Mina	SIRET	LCMDF
Competence as KSA	■	■	■	■	■	■	■	■
Competence responsibility level	■	■	■	■	■	■	■	■
Competences as learning objectives	■	■	■	■	■	■	■	■
Frameworks of competences	■	■	■	■	■	■	■	■
Conceptual facet of curriculum	■	■	■	■	■	■	■	■
Organisational facet of programmes	■	■	■	■	■	■	■	■
Classification of professions	■	■	■	■	■	■	■	■
Learner profile	■	■	■	■	■	■	■	■
Support for outstanding standards	■	■	■	■	■	■	■	■
Balance generality/expressiveness	■	■	■	■	■	■	■	■

■ Requirement fully supported ■ Requirement partially supported ■ Requirement not supported

Our model focused on enhancing the quality of competence-driven curriculum and training programmes designs, but several improvements are required to expand the scope of our approach. To support other advanced strategies such as personalised learning paths or activities (Mandin et al., 2015), a first issue relates to the lack of precision regarding the context in which a com-

petence has been developed, which is considered as important information to accurately analyse acquisition of competences (Perrenoud, 2000). Even if our model allows to distinguish between competences developed in a professional context and those developed during a training experience, it only represents a very small piece of the global context in which learning occurs (Verbert et al., 2012). In the next chapter, we propose a model-driven approach for tracking learner experience within technology-based learning environments, that can apply to enrich the learning context. However, competences may be developed and sustained during everyday life and informal learning activities. The most common solutions to informal learning gathering and validation are ePortfolios such as Mahara (Mahara, 2011), questionnaires intended to validate informal workplace learning (Kyndt et al., 2014), or social approach based on peer collaboration and assessment (Galanis et al., 2016). This variety of proposals shows that evidences about competence development have to be specified in our model, but also that interoperability with external tools is of high importance to gather competence profiles as exhaustive as possible.

Our model also lacks accurate evaluation of the learner's level of responsibility. First, this process currently stands only on the learner's grades, whereas other types of evidence such as self-assessment and observation could be used (Miranda et al., 2017). Second, learner's level of responsibility might increase or decrease depending on whether a competence is at stake intensively or not. The proposal of Fazel-Zarandi and Fox (2013) to increase accuracy of workers' competence profile by automatically updating the profile when activities occur inside the organisation, could be adapted to the educational context. One of the most difficult tasks is the definition of the rules responsible for mapping learning activities to competences. Another critical task is the specification of the rules processing the activities to infer the matching responsibility level.

Finally, additional experiments are required to evaluate the tools and run reliable usability tests and studies. The first small scale experiments already revealed that several improvements are needed regarding awareness of competence development. Open learner model visualisations such as the skill meters proposed in the Next-TELL project (Johnson et al., 2013), or grid matrix and radar charts (Kusmin et al., 2018a), should allow to increase awareness of learners' progress.

1.4 Conclusions

In this chapter, we developed innovative models, processes and tools to increase quality of learning design at two granularity levels. First, to support the development of open educational resources, we contributed to (i) the specification of a lifecycle facilitating collaborative design of OERs in complex educational settings; (ii) the specification of processes increasing quality of (automatic) metadata generation; (iii) a tool box providing awareness about OER progress and management to support the decision-making process. Second, to enhance authoring of quality HEI competence-driven curricula and training programmes, we contributed to (iv) an analytic model distinguishing between the conceptual and organisational representations to offer a new way to design different programmes targeting the same learning objectives; (v) an authoring tool driven by clear learning goals and objectives, and ensuring consistency between targeted and covered competences; (vi) a visualisation increasing awareness of learners' competence development to promote self-positioning.

One main limitation of our works relies on large scale experiments which are still required to actually validate our proposals, especially regarding the collaborative design of resources. This

can be explained by the fact that our proposals require complex educational settings, but also because adoption of OER in higher education is not a trivial process. On one hand it challenges the traditional teaching practices by introducing novelty that teachers do not always subscribe to, but on the other hand it strongly depends on teachers' involvement and personal efforts to be successful. Various investigations have been conducted to specify different open educational practices (Ehlers, 2011) that should be deployed into HEIs to boost OER adoption. Also, several authors (Sharples et al., 2009; Persico et al., 2014) emphasise the importance of evaluation. They recommend to build monitoring solutions that bring opportunities to assess usage, reuse and reengineering of educational tools and resources.

Another limitation relates to the granularity of competences we have addressed so far. Our research has until now focused on high-level competences required by training programmes and professions, and contributed to broader frameworks strengthening collaboration between universities and industry organisations (Kusmin et al., 2018b). In the COMPER project⁵, we are designing models and tools to semi-automatically recommend adaptive learning paths according to learners' profiles expressed as competences. We will address low-level competences, as the recommendations are intended for learners working autonomously during a short period of time.

These works had several implications. First, our contributions on open educational resources led us to join the consortium of the LATIn project. The aim of this European project conducted from 2011 to 2014 was to set up a collaborative methodology for the creation of open textbooks in Latin America, and resulted in more than 155 textbooks covering 23 different topics. From a more general perspective, our expertise on metadata for educational resources led us to participate in the work package 7 of the Open Discovery Space project from 2012 to 2015. In this work package, we contributed to the design and implementation of an architecture for sharing and reusing OERs at a large scale. The resulting portal⁶ currently hosts near one million resources. Second, our works on competence have been the basis for the OpenMIAGE project funded by ANR from 2016 to 2019. The aim of OpenMIAGE was to enhance the International E-Mi@ge initiative and to increase its dissemination at an international level by developing content according to the competence-based approach proposed in this chapter, and by strengthening tutoring and formative assessment of students.

1.5 Related publications

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Broisin, J., Vidal, P., Meire, M., and Duval, E. (2005). Bridging the gap between learning management systems and learning object repositories: exploiting learning context information.

⁵<https://comper.fr>

⁶<https://portal.opendiscoveryspace.eu>

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- In *Proceedings of The 2nd International Conference on E-Learning and mobile learning on Telecommunications (ELETE)*, pages 478–483, Lisbon. IEEE.
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Chapter 2

Quality-oriented monitoring of user learning experience

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2.1 Introduction

Adaptive learning systems are designed to do better than to align learners to the same learning content by engaging them with teaching strategies and material that tailor their prior knowledges, needs, goals and motivations (Shute and Zapata-Rivera, 2012). Adaptation of educational processes can be organised into two approaches: individualised learning and personalised learning (Verpoorten et al., 2009). In case of individualised learning, educational resources and activities are adapted to the goals and needs of each learner according to her characteristics. In case of personalised learning, learners select the resources that best fit their needs after engaging in critical self-reflection on their learning and objectives. In this work, we use "personalisation of learning" to refer to both types of adaptation, individualised and personalised.

Even if self-reported data are sometimes used for adaptation purposes, adaptive systems often ground their adaptation logic on data reflecting interactions of users with digital artefacts. Interaction data are of very different natures, ranging from social metadata resulting from

intentional contributions of users, to usage data automatically collected by the system in the background. Social metadata include comments, tags, ratings, bookmarks, discussions, reviews, etc. Usage data reveal interactions between users and learning systems, and include creation of a new course, integration of an activity into a learning scenario, submission of an assignment, etc. Also, two different types of data have to be considered. First, those resulting straight from the gathering process, sometimes called raw data. These data require further processing to be usable and meaningful for adaptation purposes. Second, inferred data, or indicators, that are derived from transformations, aggregations and other processes operated on the raw data. Therefore, in order to build efficient adaptive learning systems, we have been advocating that it is of most importance to design models able to represent both the collected and inferred data, but also to develop monitoring systems able to ensure the actual gathering of data.

Knowledge-based learning environments, defined as systems standing on various static and dynamic information about users to trigger adaptation actions ([Grandbastien and Nowakowski, 2014](#)), have developed a wide range of models describing interaction data. These models come either from proprietary initiatives, or from standardised solutions. As shown later in this chapter, knowledge-based systems often focus on a given type of data only (e.g. social metadata or usage data), implement solutions tightly coupled to a given context or adaptation purpose, or do not take into account inferred data. On the other hand, monitoring systems have been extensively investigated in the network and system management area. Management of processes running on an operating system, of physical resources hosted by a computer, or of traffic over a network attracts a wide community of researchers. An important line of research in this field is to design monitoring systems able to self-adapt their behaviour according to quality specifications often expressed via service level agreements (SLA) that might change over time. However, this self-reconfiguration is most of the time held through ad-hoc logic unsuitable for reuse in other scenarios, and also unable to satisfy high level objectives.

Our approach to contribute to adaptive learning systems consisted in increasing the quality and heterogeneity of data required by such systems. We proposed and combined advances in both knowledge-centred environments, and system and network management. The research we conducted focused on providing a framework featuring collection, storage and sharing of data reflecting past and current learning experiences of learners. Our objective was to ensure that quality of data meet adaptive systems requirements so that intelligent algorithms built on top of these data are as relevant as possible. Also, we developed our research with the objective of preserving privacy of users, as the data collected in the educational context reveal sensitive information. To reach these objectives, we adopted a model-driven approach to represent the data to collect and to deploy the components responsible for their management. The remaining of this chapter exposes the context of our research before introducing and discussing our main contributions: a unifying information model able to federate heterogeneous data, a privacy-aware architecture based on a data-splitting approach, and a methodology to help human operators designing quality-oriented and self-adaptive monitoring systems.

2.2 Research context and questions

In her Ph.D. thesis, [Lefevre \(2009\)](#) identified five main facets to personalise TEL systems: (1) the learning activities, (2) the learning paths, (3) the features available within the system, (4) the

different human-computer interfaces of the system, and (5) the remediation actions suggested to learners. In order to allow these adaptation processes, many artificial intelligence approaches have been explored (Markowska-Kaczmar et al., 2010). These approaches have proposed, on the one hand, to better identify the learners' characteristics and needs; on the other hand, to improve the personalisation mechanisms or tools to support students self-reflective activities (Lefevre et al., 2012). Our works have a strong focus on the first line of research, even if we developed adaptive systems featuring personalised assistance or recommendation of learning resources.

Whatever the type of adaptation implemented by the learning system is, we consider adaptation as the process, or loop, illustrated in Figure 2.1. It is composed of three distinct phases: (1) the monitoring of users' activities through dedicated sensors in order to build the **Knowledge** representing the state of the learning situation to adapt, (2) the data analysis in order to find out remediation actions to apply, and (3) the execution of the identified actions on the learning situation. Besides, this loop can follow two different paths: the second and third phases can be processed either manually or automatically. Manual adaptation is handled by users that adapt learning activities according to various indicators provided by dedicated dashboards and visualisations (Verbert et al., 2013). Various systems provide diverse dashboards through which teachers and learners visualise the learning process and engage manual adaptation actions such as class or group interventions (Segal et al., 2017), selection of alternative course material, interventions on learning design (Bakharia et al., 2016), or recommendation of specific activities (Ferguson and Shum, 2012). These systems perform generally well, since they are designed for a specific situation and expose to users the exact information they need to make the appropriate decision. On the other hand, automatic adaptation consists in continuously analysing users' activities to infer the needs of each of them at any moment, and then to automatically apply some adaptation mechanisms through actuators. Let us note that other research proposes semi-automatic systems by combining both manual and automatic approaches (Guin and Lefevre, 2013).

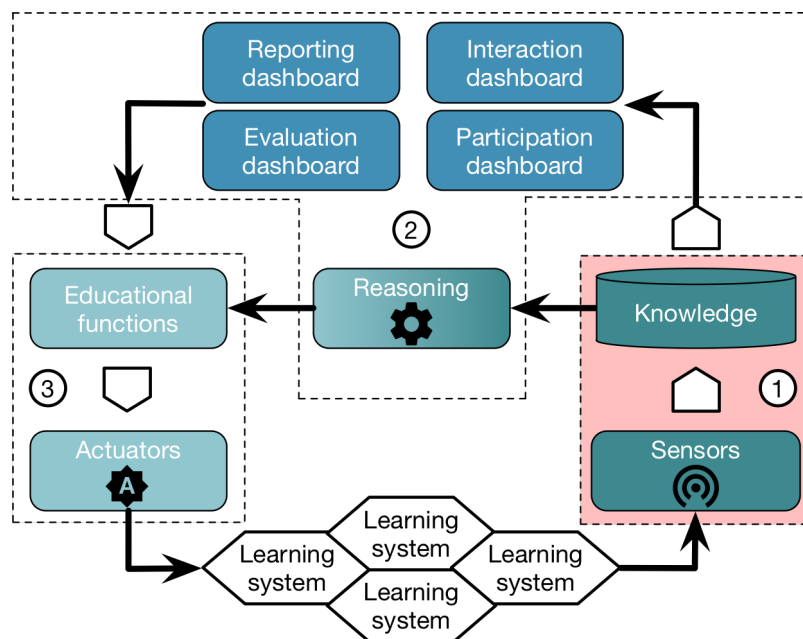


Figure 2.1. Adaptation of TEL environments.

Our works have focused on investigating the first phase of the adaptation process, because wrong decisions might be taken by educators and/or adaptive engines if the data provided by the monitoring process do not reflect accurately the actual user experience. These data do not include domain-dependent (e.g. knowledge regarding the topics to be studied) and -independent (e.g. demographic, previous background, interests, goals) information only, they also depict past and current experiences of the user (Magoulas et al., 2003). Our vision of Knowledge, the user learning experience, is illustrated in Figure 2.2 and includes three different facets: the facet Environment represents the systems and resources that have been in the focus of user; the facet Activity refers to the activities carried out by user on the environment; the facet User provides individual and personal information. In the remaining of the document, the user learning experience is also referred to as user attention metadata, or simply attention metadata (Duval, 2011).

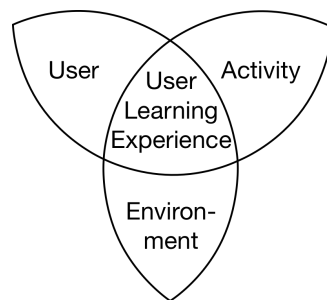


Figure 2.2. The user learning experience.

Our objective was to build an attention metadata model providing as much comprehensive information describing learning experiences as possible, while being as flexible as possible to integrate the widest range of learning experiences. The federation of data resulting from interactions between users and a wide range of tools increases accuracy, completeness, and thus usefulness of the user learning experience (Lafraquiere et al., 2006). Hence, to federate at a large scale the monitoring of users' learning activities, our works have tackled the following research questions (see the introduction chapter):

- RQ 1: How to design a learning experience model able to federate highly heterogeneous data while preserving their semantics?
- RQ 2: How to support processing and sharing of meaningful indicators?
- RQ 3: How to ensure privacy of users?

We addressed this question by adopting the management approach by the Distributed Management Task Force (DMTF), a standards organisation in management area. This approach stands on a common information model to represent the managed elements (DMTF, 2010), and provides specifications to ensure discovery, access and manipulation of these elements (DMTF, 2012). We extended the core models to design an expressive and extensible model of user learning experience integrating definition of indicators, and set up a privacy-aware architecture compliant with the DMTF specifications to manage these data.

Also, to make the user learning experience as accurate as possible, we investigated quality of information (e.g. correctness, freshness, timeliness, accuracy, etc.) collected by the monitoring process by addressing the two following questions already given in the introduction chapter:

RQ 4: How to propose a methodological approach able to ensure quality of the monitoring system?

RQ 5: How to assist human administrators in the design of adaptive monitoring strategies according to quality objectives?

Our objective was to design a monitoring solution able to satisfy a given quality of service regarding the monitoring itself. To face this challenge, we adopted the Requirements Engineering methodology. It starts from high-level goals, and ends up with the (re)configuration of monitoring mechanisms. However, identifying goals representing the "starting point" for deriving monitoring (re)configuration is a big challenge. Besides an adaptation methodology, we proposed several monitoring adaptation patterns to assist human administrators in designing meaningful adaptations that increase the overall quality of the monitoring system.

2.3 Contributions

2.3.1 A framework dedicated to user learning experience

The research presented in this section tackles RQ1, RQ2 and RQ3 to facilitate federation, collection and reuse of attention metadata produced by users interacting with heterogeneous learning systems, and to ensure their privacy. This research was strongly tied to some findings of my Ph.D. thesis related to tracking of learning objects usage, and have been mainly developed during Valentin Butoianu's Ph.D. thesis (2013) in the context of the CEAGMATIC project funded by ANR from 2007 to 2010. Before going into the details of our main contributions, the next paragraph gives the requirements that drove the design of our solutions.

Concerning the data model, it should describe at a high level of resolution the *three facets* of the user learning experience by providing *semantic information* about the context in which the learning tasks have been carried out, but also feature *extensibility* to cope with the specificities of the various learning environments and activities. The model should also include *built-in indicators* described by human- and machine-processable *metadata* to become meaningful to both stakeholders and adaptive engines, as well as to allow the *reuse of the algorithm* and *their values*. Concerning the supporting architecture, in addition to feature *scalability* to manage a large amount of data, it should be as open as possible to facilitate gathering of the users' learning experiences, but also to facilitate data *sharing*. The architecture should also provide tools to support educators in the *design of indicators* so the system meets their needs. Besides, as attention metadata comprise personal data defined as "*any information relating to an identified or identifiable individual (data subject)*" according to the OECD ([Organisation for Economic Co-operation and Development, 2013](#)), the architecture should be able to prevent *user privacy* disclosure without compromising the personalisation process.

2.3.1.1 High-resolution representation of user learning experience

The user learning experience model we designed ([Butoianu et al., 2009, 2010](#)) is illustrated in Figure 2.3 and includes three interlinked submodels matching with the three facets of the user

learning experience: the User model, the Environment model, and the Activity model. The environment model comprises information about the digital artefacts that have been in the focus of the user at any moment. It allows to describe and classify learning systems and resources into two root classes (i.e. *ApplicationSystem* and *Resource*), and includes aggregation relations to add semantics between these types of entities. The activity model describes how users interact with learning environments. Besides, the type of actions carried out by users (e.g. search, view, download, tag, rate, comment, etc.), the time when the system or resource was in the focus of the user, or the duration of the attention, are exposed in the activity model as well. Both the environment and activity models are connected to the user model through associations in order to create triples $\langle \text{User}, \text{Activity}, \text{System|Resource} \rangle$.

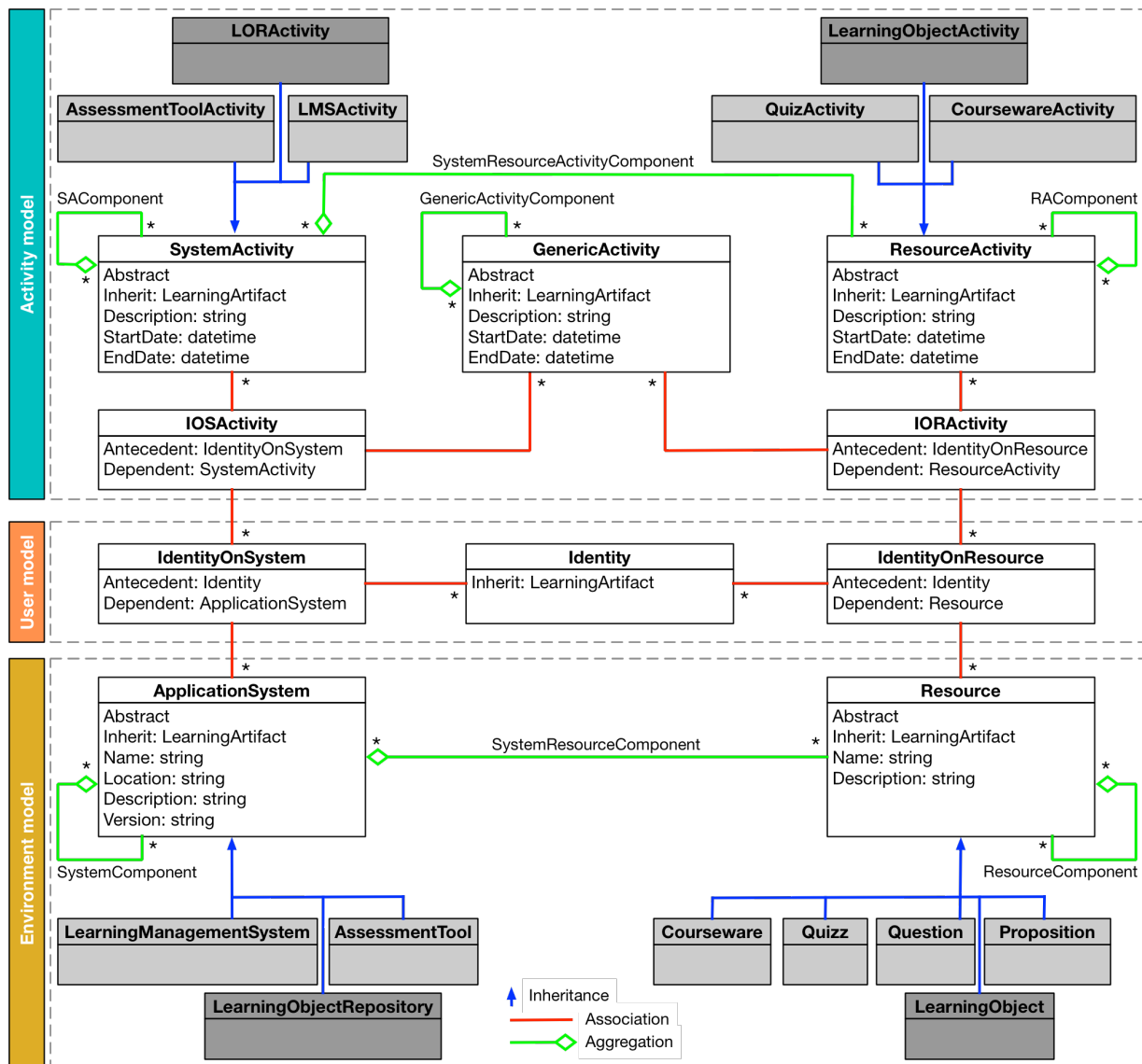


Figure 2.3. Modeling of the user learning experience.

Our user model (Ramandalahy et al., 2009b) is detailed in Figure 2.4. An *Identity* identifies a user and represents the starting point for retrieving her profile. An identity is characterised by

Personal Information about the user such as the first and last names, e-mail, preferred languages and accessibility needs. One originality of our approach stands on the opportunity to describe an identity according to the role of the user in a given learning situation. This proposal unifies various information in a single user model and allows for adaptation of tasks whatever the role of the user is (e.g. learner, teacher, tutor). The abstraction `ProfileCore` represents the top-level class to design such profiles, and we have until now focused on the learner profile represented by the class `LearnerCore` in Figure 2.4. For interoperability reasons, this profile complies with the Learner Information Package specification¹ and gives details about the actual knowledge of a user regarding the concepts of a given ontology (see Section 2.3.1.4), her general interests and goals, as well as degrees awarded by official institutions.

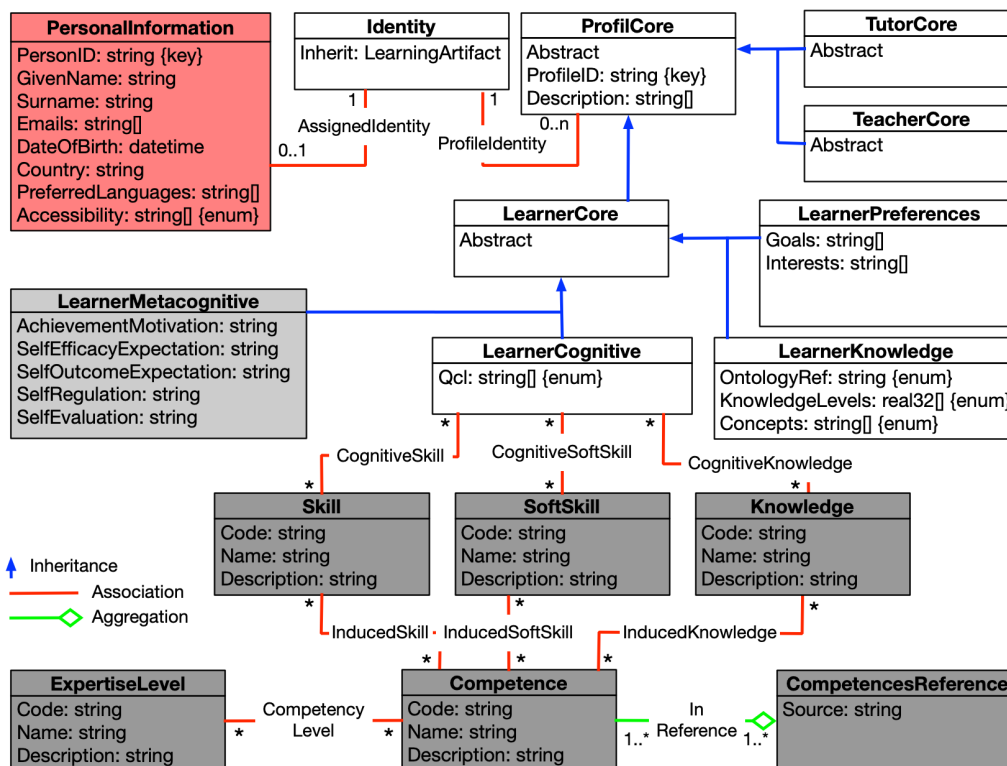


Figure 2.4. The user model.

The core models aim at providing a common basis for representing interaction data resulting from activities performed by users on learning systems and resources. To demonstrate their usability, we developed several extensions to meet specific objectives. As part of the CEAGMATIC project, whose goal was to design and experiment a metacognitive guidance tool enabling students to appropriately use assistance (see Section 2.3.1.4), we extended the environment and activity models to take into account actions specific to learning management systems and questionnaire tools. We also designed a learner metacognitive profile aiming at measuring how a learner thinks about her cognitive skills. These extensions appear in light gray in Figures 2.3 and 2.4. Also, the research we conducted in the COMPETENCE project (see previous chapter) led us to model learning object repositories and matching activities, and to extend the learner cognitive profile with a competence profile. These extensions appear in dark gray in Figures 2.3 and 2.4.

¹<http://www.imsglobal.org/profiles/>

2.3.1.2 The indicator model

The user learning experience model intends to reflect interaction data. On their basis, concrete information, or indicators, can be inferred to expose data that can be understood by learners and instructors, and that can be used for automatic adaptation purposes as well. Indicators provide a simplified representation of the state of a complex system (Glahn et al., 2007). They can be of different nature, depending on the learning goals, actions, performances, outcomes as well as the situation in which the learning process takes place (Florjan et al., 2011).

Our indicator model (Butoianu et al., 2012) computes valuable information in relation to any artefact of the user learning experience model. It is illustrated in Figure 2.5 and comprises two main classes that clearly separate semantics of indicators, and their values. `IndicatorDefinition` behaves as a pattern specifying the objectives and usage of an indicator. It includes, among other data, a human readable description of the indicator usage, its data type and units, and the algorithm leading to the calculation of its value(s) by the underlying instrumentation. The composition relationship allows reusing indicators' definitions for designing high-level indicators standing on the definitions of lower-level ones. The other main class `IndicatorValue` holds the value(s) of the indicators. Its attributes specify the time when a value has been computed and the value itself, but also define whether the current value must be updated when a new result is calculated, or if a new value instance has to be created. Finally, to associate indicators to any entity of the user learning experience model, two associations link indicators' definitions and values to the root class `LearningArtefact`, respectively.

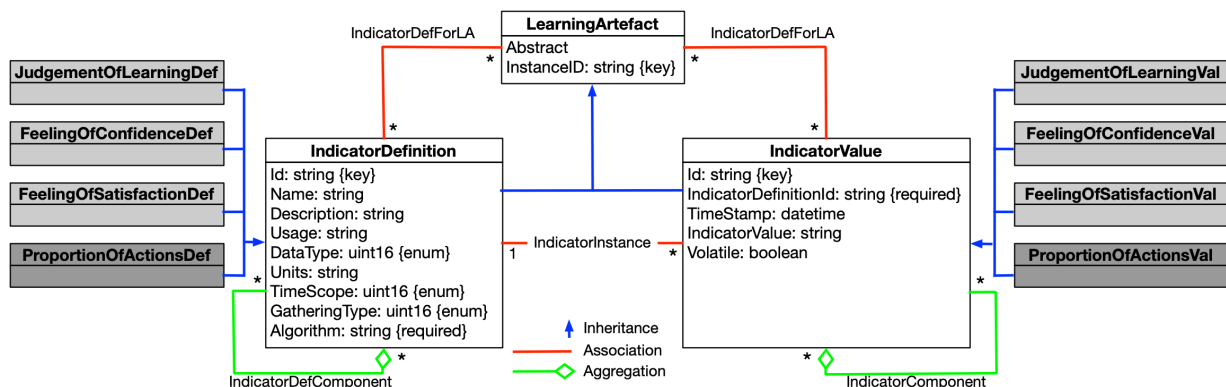


Figure 2.5. The indicator model.

The indicator model allows to define a wide variety of more or less complex statistical and arithmetical indicators, and has been validated in two different contexts. In the COMPETENCE project, among various statistics such as the total number of consultations, downloads or ratings for a given learning object or course, we defined the "proportion of actions" indicator appearing in dark gray in Figure 2.5. This indicator calculates the amount of activities carried out by each member of a group during a collaborative learning process. The second validation was conducted within an experiment of the CEAGMATIC project. Learners were asked to fill the Motivated Strategies for Learning Questionnaire (MSLQ), a self-report instrument designed to assess college students' motivations and the way they use different learning strategies (Pintrich and De Groot, 1990). On the basis of their answers, we defined and computed several metacognitive indicators appearing in light gray in Figure 2.5.

2.3.1.3 Privacy-aware architecture

The Web-Based Enterprise Management (WBEM) architecture by the DMTF stands on three main components. Providers interact directly with the systems being tracked, or managed elements, to get the value of a specific information regarding a process, resource, or device. Clients and listeners send requests and receive responses, events and alarms occurring on the managed elements. Managers host a repository containing the management knowledge provided by the providers as instances of the model, and orchestrate the workflow between components by redirecting requests, responses and alarms. This architecture ensures isolation of both clients and providers that can be designed independently of each other.

Starting from the WBEM architecture, we designed our own architecture to fulfil the requirements defined in Section 2.3.1, including privacy issues. We also studied good practices from the security area, and identified a general principle to manage sensitive data that consists in storing information into different locations instead of using a single information system. The risk that someone gets an overview of the whole set of information is very low (Borcea et al., 2005).

Our conceptual architecture (Butoianu et al., 2011c,d) is illustrated in Figure 2.6. The sensitive data of the user model, and especially the personal information that reveals the user's identity, are stored into a local repository (i.e. a local manager), whereas the environment and activity models, as well as the learner profile, reside on a central manager. This component thus holds the activities carried out on systems and resources, as well as the profiles of the users who performed these activities, but does not host their identity. Therefore, it is not subject to privacy concerns (Kobsa, 2001). The central manager also features indicators subscription, calculation and delivery, and facilitates publication and retrieval of attention metadata through a dedicated API (Butoianu et al., 2011b). Adaptive learning systems represent both the managed elements and the system to be adapted. Hence, they embed both, sensors acting as providers to extract attention metadata when an activity occurs on the system, and actuators acting as clients to retrieve data from the central manager and launch adaptations when needed. Since we adopted the publish-subscribe messaging pattern to deliver indicators' values as soon as they are computed by the central manager, learning systems also embed indicator subscribers and listeners. Finally, the toolbox includes end-user applications to extend the data model and design new indicators. It also proposes dashboards and visualisations to get an overview of users' learning experiences.

At the functional level, a common information must be shared between the local and central managers to make adaptive components able to retrieve attention metadata of a given user. We adopted the pseudonymous identification which allows to differentiate users without revealing their identity (Flinn and Maurer, 1996), and interconnect successive experiences for long-term personalisation. The `PersonID` of the `PersonalInformation` stored into the local manager matches with the `InstanceID` of the `Identity` recorded in the central manager. Transfer of this information between the components of the architecture is handled through a cookie of the user's browser.

2.3.1.4 Adaptive tools built upon the experience framework

To validate our framework when it comes to manage various user learning experiences, but also to show its ability to support near real-time adaptation, we implemented several sensors and adaptive components serving different needs into existing learning systems. Relevancy of these experimental proposals and their impact on learning is out of the scope of the validation process.

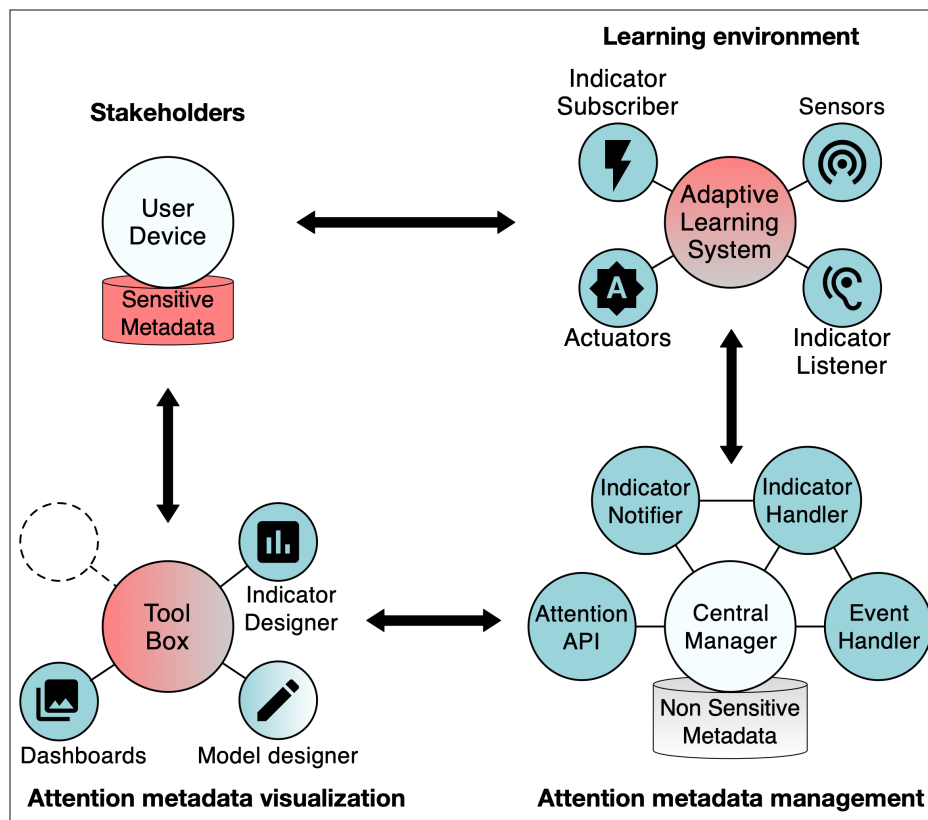


Figure 2.6. The privacy-aware conceptual architecture.

Intelligent Tutoring System. In the CEAGMATIC project, we investigated the influence of learners' metacognitive profile when accessing hints and help seeking resources during a learning task. Learners' judgment of learning, feeling of confidence, and feeling of satisfaction were the metacognitive indicators studied in this research (Ramandalahy et al., 2010b). We built an assistance system called MetaCTAT based on the Cognitive Tutoring Authoring Tools elaborated by the Carnegie Mellon University (Alevén et al., 2006b). MetaCTAT generates multiple choice questions and triggers adaptive actions (Ramandalahy et al., 2010a). When learners are engaged in a wrong learning path, it recommends hints according to the model of desired help-seeking behaviour (Alevén et al., 2006a). Hints, glossaries and learning resources recommended to learners when they submitted a wrong answer were located in the project's Moodle server.

In this case study, we extended the user learning experience model to meet the specificities of the learning tasks involved in the experimental scenario (Ramandalahy et al., 2009a), and implemented sensors to monitor users' activities within both MetaCTAT and Moodle. Since all interactions between learners and these systems were recorded into the central manager, it exposed complementary data about the learners' profiles. Their metacognitive profile was inferred from the data provided by MetaCTAT, whereas their cognitive and preference profiles were brought by Moodle. We designed a profile management prototype to visualise learners' profiles in an accurate and comprehensive way (Ramandalahy et al., 2009b,c).

Personalised recommender systems. We proposed in (Broisin et al., 2010) a semantic-based solution to recommend learning objects according to the documents accessed by users.

This solution was integrated into the Ariadne Finder, the search engine for learning resources of the Ariadne foundation. The result was a personalised recommender system able to recommend learning resources according to (1) attention metadata collected when a user performs an activity (e.g. search, consultation or download of a resource), (2) user and resource models described in terms of ACM annotations, and (3) a content-based recommendation algorithm able to calculate similarities between these models.

The originality of this approach relied on the monitoring of users' conceptual navigation through the ontology, instead of supervising their site navigation. For each resource accessed by learners, the weights associated to the ontology concepts in the model of that resource are incremented to users' current goals. The recommendation algorithm implements the k-nearest neighbours algorithm (Salton and McGill, 1986) to identify the resources to be recommended, according to the "stronger" concepts the user is paying attention to. Another recommendation algorithm was designed in (Butoianu et al., 2011a). Its logic also stood on the the k-nearest neighbours algorithm but, in this study, it explored the learner profile according to the current learner interests expressed through the significant words of the resources' titles she accessed, and using the gradual forgetting function introduced by Webb and Kuzmycz (1995).

2.3.1.5 Discussion and positioning of the works

The research community started investigating collection and reuse of attention metadata in the late 2000s. With the growing interest for Learning Analytics, several standardisation efforts emerged since 2010. We discuss here the initiatives that intend to share heterogeneous attention metadata at a large scale, no matter the adaptive purposes.

Table 2.1 exposes the results of the study we conducted. Our review of literature shows that each project addresses the three facets of the user learning experience, even if most of them do not suggest an education-centric user profile. Also, the reviewed models often offer poor semantics, which may result in the design of ad-hoc data structure as model designers may not be aware of fundamental design concepts (Goodwin et al., 2016). Instead, the UML makes our model easy to read while providing semantic details and built-in constraints. Table 2.1 shows that projects developed by the research community have poor extensibility capacities (instead, they are flexible in terms of vocabulary). For exemple, the data models specified by the Contextualized Attention Metadata (CAM) initiative (Schmitz et al., 2011) and the NSDL Paradata project² (Niemann et al., 2013) are restricted to a predefined set of activities and are not meant to be extended. At the opposite, the standardisation efforts supported by the World Wide Web Consortium, Advanced Distributed Learning (ADL) or IMS Global Learning Consortium, build on high-level proposals allowing for almost unlimited extensibility.

With regards to indicators, Table 2.1 highlights an important gap. Indicators management seems out of the scope of the ongoing standards. Their approach consists in offering external and ready-to-use tools able to compute and visualise indicators on request, but the lateres are not recorded into the repository and can not be shared and reused. Some research programmes such as Usage Tracking Language (Ngoc et al., 2009) and its extension Data Combination Lan-

²<https://nsdl.oercommons.org/>

³<https://www.w3.org/TR/activitystreams-core/>

⁴<https://www.imsglobal.org/activity/caliper/>

⁵<https://github.com/adlnet/xAPI-Spec>

Table 2.1. Positioning of our approach in relation to other initiatives.

		Experience model					Indicator model					Architecture		
		User model	Environment model	Activity model	Semantics	Extensibility	Built-in model	Metadata	Design support	Reuse of algorithm	Reuse of value	Sharing	Scalability	Privacy
Research programmes	CAM	■	■	■	■	■	■	■	■	■	■	■	■	■
	UTL-CL	■	■	■	■	■	■	■	■	■	■	■	■	■
	TBS-IM	■	■	■	■	■	■	■	■	■	■	■	■	■
	Learning Registry	■	■	■	■	■	■	■	■	■	■	■	■	■
	NSDL Paradata	■	■	■	■	■	■	■	■	■	■	■	■	■
	LCDM	■	■	■	■	■	■	■	■	■	■	■	■	■
Stand. efforts	Activity Streams ³	■	■	■	■	■	■	■	■	■	■	■	■	■
	IMS Caliper ⁴	■	■	■	■	■	■	■	■	■	■	■	■	■
	xAPI ⁵	■	■	■	■	■	■	■	■	■	■	■	■	■
Our approach		■	■	■	■	■	■	■	■	■	■	■	■	■

■ Requirement fully supported
 ■ Requirement partially supported
 ■ Requirement not supported

guage (Ngoc et al., 2010), the Learning Context Data Model (LCDM) proposal (Lukarov et al., 2014; Thüs et al., 2015) or TBS-IM, a trace-based system able to calculate collective and individual indicators in Moodle (Djouad et al., 2010; Djouad and Mille, 2018), include solid capacities to define indicators and reuse their values. TBS-IM and LCDM propose advanced user-centred tools to help educators defining their own indicators, even if important efforts are still required (Muslim et al., 2016). Another significant observation is that no proposals, but TBS-IM, offer the opportunity to reuse algorithms defined for computation of indicators values. This may explain why recent research undertaken in the HUBBLE project⁶ started investigating how to facilitate sharing and reuse of analytics algorithms between tools (Lebis et al., 2016, 2017; Lebis, 2019). More research on this topic could encourage the community to adopt a common and technology-independent representation of algorithms that would help scientists to focus on data exploration and combination, instead of redefining and refining existing mining techniques.

Prior works adopted a distributed and scalable architecture to support the data models. CAM, Learning Registry (Bienkowski et al., 2012) or NSDL Paradata expose API and/or OAI-PMH data providers. However, the systems we reviewed are poorly featured regarding user privacy. Most of them simply neglect this crucial facet of attention-aware systems. As an example, except OAuth authentication and authorisation, all Experience API (xAPI) security features are "left to the individual LRS provider as an implementation detail"⁷. Yet, Hoel et al. (2017) show on their study how data protection and privacy frameworks are going to influence soon the design of adaptive systems based on attention metadata. Only one system takes actions to address

⁶<http://hubblelearn.imag.fr/>

⁷<https://github.com/adlnet/xAPI-Spec/blob/master/xAPI-Communication.md#partthree>

some privacy principles like notice and consent, purpose or access. However, CAM may reveal identity of users, as the personal information link to external profiles. Projects that fully take into account user privacy are those like NSDL Paradata which do not collect personal information about users. Our approach to the privacy issue stands on both the distribution of sensitive and non sensitive data, and the adoption of an anonymity technique preventing disclosure of users' identity. At first sight, data stored into the central repository do not allow to identify users, as no information in relation to their personal information is provided. Yet, at a closer look, a question arises: may a big amount of interlinked learning experiences reveal users' identity? The more learning applications and resources are covered by the experience framework, the more detailed information about users are made available, and the higher the chances to identify users are.

2.3.2 A methodology for quality-oriented self-adaptive monitoring

This section tackles RQ4 and RQ5. The overall objective of the works was to increase the quality of the data gathered by the monitoring process and exposed to adaptive systems. To reach this objective, we investigated how to build a quality-oriented monitoring system, and proposed a methodology to make monitoring systems self-adapt according to high-level quality objectives. Notice that these works go beyond learning adaptive systems and may apply to any other type of adaptive environment. In fact, this research has been initiated during Antoine Toueir's Ph.D. thesis (2014) in the context of the IMAP project which studied self-management and self-reconfiguration of onboard aircraft systems according to a predefined quality of service.

2.3.2.1 KAOS4SAM: a goal-oriented methodology

We adopted a Requirements Engineering (RE) approach to introduce intelligence into the monitoring system. The origin of RE goes back to the need of avoiding crucial mistakes at the project design phase. This methodology applies iterative activities about "*eliciting, evaluating, documenting, consolidating and changing the objectives, functionalities, assumptions qualities and constraints that the system-to-be should meet based on the opportunities and capabilities provided by new technologies*" (Van Lamsweerde, 2009, p. 55). In our context, RE guides the design of platform-independent monitoring adaptation logic.

Among the various methods following the RE principles, Keep All Objectives Satisfied (KAOS) represents the leading methodology for goal-oriented modelling. The software design process is driven by the identification of high-level *objectives* to achieve, which are then mapped to *goals* to realise. The *leaf goals*, or *requirements*, result from successive refinements of all higher-level goals and represent the lowest level of the refinement tree. A goal is labeled as requirement if it can be assigned to a specific *agent* (i.e. computer component or human operator). We adopted the KAOS methodology because (i) it proposes a clear roadmap to explicit the objectives of the system, (ii) it focuses on the real problems of the system, (iii) it ensures a vertical consistency between high-level objectives and low-level concrete actions, and (iv) it allows to identify actions that can be reused by other systems in other contexts.

Our methodology, named KAOS for Self-Adaptive Monitoring (KAOS4SAM), is illustrated in Figure 2.7 and comprises three distinct steps. The first step provides a set of high-level models of goals representing guidelines that ensure achievement of predefined objectives, and that can be reused to address other monitoring needs. Even if our research aimed at providing self-

adaptive monitoring with additional features such as integration, decentralisation, evolutivity or genericity (Toueir, 2014), we focused on the quality-driven adaptation of monitoring. The quality facet of adaptation relates to the capacity of monitoring to self-adapt according to high-level quality objectives about the monitoring itself. The second step of the methodology refines the matching high-level goals into low-level but still platform-independent requirements in order to support human administrators to design a specific self-adaptive monitoring system. Here, our approach lied on a set of patterns primarily designed to achieve quality objectives, but that can be reused for other purposes. In the last step, the patterns and requirements are selected from the set of models according to the specific objectives to achieve and problems to avoid, and then the final refinement tree that will be implemented within the actual monitoring system is built. These three steps are exposed in the next sections.

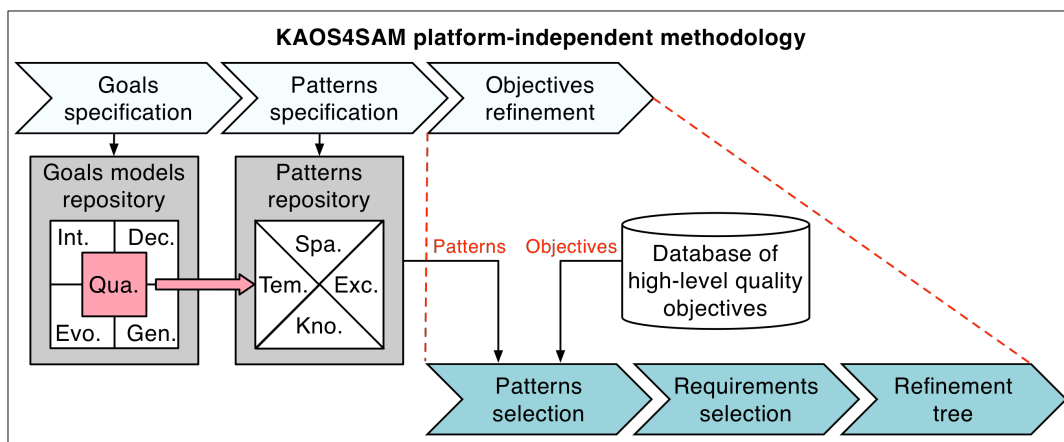


Figure 2.7. Overview of the KAOS4SAM methodology.

2.3.2.2 Quality-oriented model of goals

The first step of the KAOS4SAM methodology consists in refining each high-level monitoring objectives in order to identify the low-level goals to achieve, but also the agents able to take charge of their completion. All of our models designed using the KAOS graphical language (Van Lamsweerde, 2009) can be found in (Toueir, 2014), here we only detail the model of goals dealing with quality of monitoring and illustrated in Figure 2.8.

The quality criteria deal with: (1) the monitoring itself, in order to provide functional systems (e.g. adaptive environments, management systems, etc.) with the data they need to complete their tasks, and (2) the adaptation of this monitoring so that it is able to self-adapt according to quality objectives. Therefore, this high-level objective is AND-refined into two goals to make the monitoring functionalities, but also the adaptation of monitoring, quality-driven. The first goal is then AND-refined into two requirements under the responsibility of the monitoring architect. The requirements specify quality objectives in a computer-processable form, and then map these objectives towards the matching monitoring configuration. The second goal is AND-refined into one goal and one requirement: the goal relies on the quality-oriented facet of the monitoring functionalities, as it represents the core capacities to be able to configure monitoring, whereas the leaf goal is under the responsibility of human administrators and deals with the identification of the quality objectives of the monitoring itself.

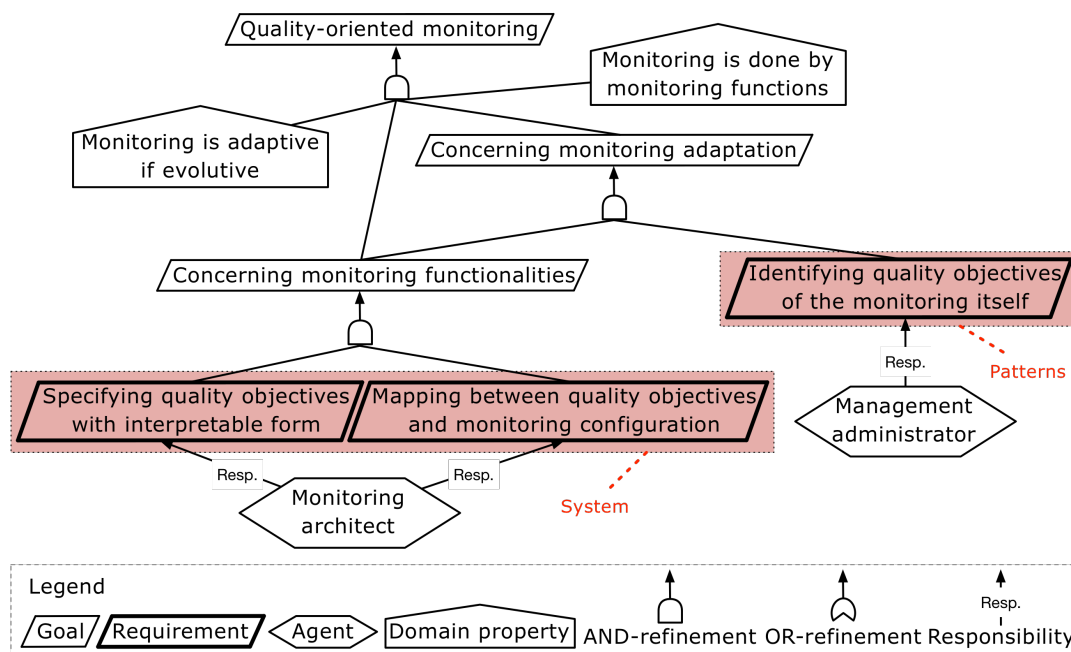


Figure 2.8. The model of goals for quality-oriented monitoring.

Figure 2.8 shows that human administrators have to manually handle the refinement process leading to the identification of the quality requirements of monitoring adaptation. Therefore, we investigated aspects of monitoring that may be subject to adaptation and established, as a result, a number of leaf goals classified into four distinct categories, or dimensions (Toueir et al., 2013): Exchange, Knowledge, Temporal, and Spatial. We then proposed monitoring adaptation patterns falling into those categories and intended to assist human administrators in the refinement task.

2.3.2.3 Patterns for quality-oriented self-monitoring

The design of patterns relies on predetermined correct and complete KAOS refinement patterns mathematically proven (Darimont and Van Lamsweerde, 1996). In Figure 2.9, the Milestone pattern identifies one or several intermediate goals that must be achieved orderly before completing the goal they refine, whereas the Case pattern identifies the set of different and complete cases for reaching final goals that OR-decompose the high-level goal.

Exchange pattern. This pattern illustrated in Figure 2.9 (Toueir et al., 2014b) refers to exchange of information through a management protocol between a source and a target. It aims at overcoming problems related to data collection and delivery. Communication inside monitoring systems may occur between a manager and an agent, between two managers, or between a manager and a shared database. The first refinement level addresses this property by refining the Exchange dimension into the three matching goals. The second refinement level covers all possible push and pull communication modes, whereas the third level takes into consideration the two different types of actions that may be executed: the use of the current exchange mechanisms, or the modification of these mechanisms. Finally, according to the triple $\langle \text{Source}, \text{Target}, \text{Protocol} \rangle$, the last refinement level defines the requirements eliciting the exchange entities that are subject to adaptation, together with the adaptation actions to be applied to achieve the goal they refine.

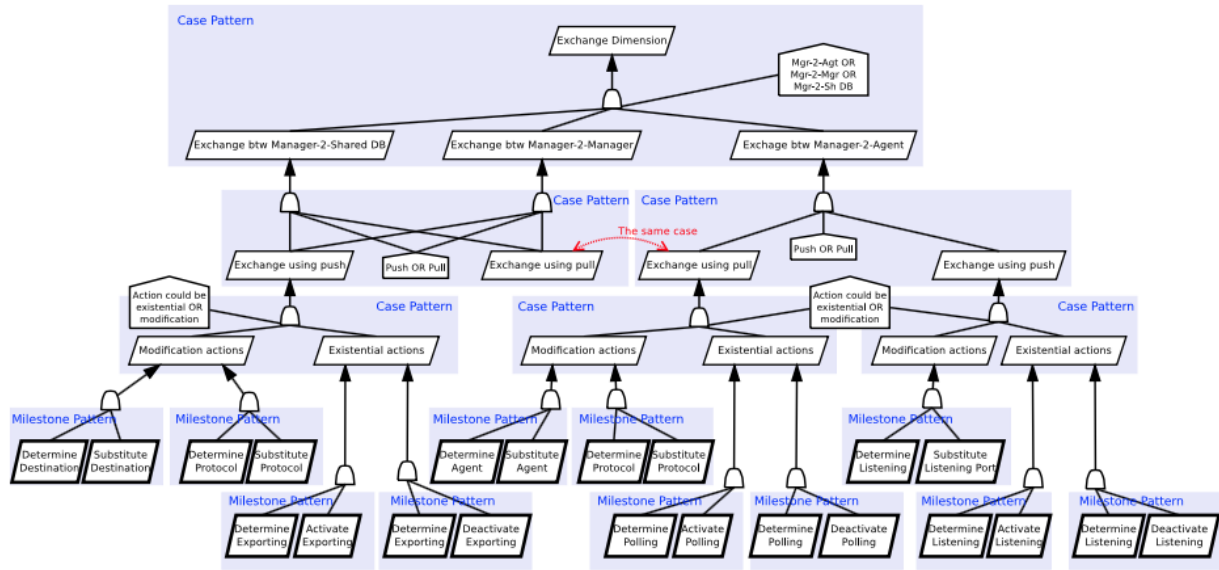


Figure 2.9. Modelling of the Exchange pattern (Toueir et al., 2014a).

Knowledge pattern. To be able to make wise decisions, monitoring managers need to instrument specific metrics at runtime and according to the adaptation needs. The Knowledge pattern thus intends to balance the trade-off between building a richer knowledge and controlling the monitoring costs, and allows for definition and activation of new metrics as well as deactivation of existing ones. In that case, metrics are not necessarily discarded, rather their instrumentation could be transferred to another collaborative manager on which they are activated. Indeed, as large scale monitoring systems involve the collaboration of multiple managers, the pattern allows to act on the management perimeter of all peers, by focusing on the duplication and delegation processes that bring metrics management flexibility. The detailed Knowledge pattern can be found in (Toueir et al., 2014a) or (Toueir, 2014).

Temporal pattern. The Temporal pattern deals with all time-related facets of the two previous patterns. It handles temporal violations related to both metrics collection and delivery, and scheduling of the underlying exchange mechanisms. Regarding exchange of information, we distinguished two levels of temporal granularity. The fine-grained level deals with individual pollings between a source and a target, as well as exports towards a database. The coarse-grained level addresses collective pollings and exports. Based on this distinction, we identified various requirements to update the frequency of a given polling/export, to launch a set of synchronised parallel pollings/exports, or to launch pollings/exports according to a relative offset. Regarding metrics, we addressed the possibility of updating the time scope interval covered by a metric value, or the freshness of a metric value. The detailed description of the Temporal pattern is also available in (Toueir et al., 2014a) or (Toueir, 2014).

Spatial pattern. Since the number of users consuming the services provided by the functional system may fluctuate rapidly, the monitoring system has to self-adapt to the number of managed resources. Through the Spatial pattern, we considered the monitoring scope of each manager in order to react to important changes regarding the amount of resources to monitor. We distinguished two different scenarios. For managers acting on their own monitoring perimeter,

we identified several requirements to add and remove resources from the managed scope. To take into consideration managers acting on peers' perimeter, we suggested several refinement levels to perform actions on running managers (i.e. add and remove managed resources), but also to deploy new managers and to assign them a given monitoring scope (Toueir et al., 2014a).

The patterns we specified in this section identify a set of fine-grained requirements (i.e. adaptation actions) that can be further reused and mixed together to satisfy high-level quality objectives in a real-world monitoring context. These patterns represent the first step towards a common basis allowing for integration of quality features into monitoring systems, even if the list of actions presented here is far from being exhaustive and static. Instead, other (re)configuration proposals applying to monitoring systems can be further developed by the community to enhance the completeness of the patterns repository.

2.3.2.4 Case study: quality-driven adaptation in a cloud provider

The last step of our methodology consists in selecting the patterns according to the objectives of the monitoring system to be designed, and building the final refinement tree. Here a case study illustrates the design of a quality-oriented monitoring system for a cloud provider.

Context and high-level objectives. Our scenario was related to the work detailed in Chapter 3 about computer education, where a datacenter deployed virtual machines (VM) on demand to provide students with remote laboratories. The aim of the monitoring system was to collect management data from the VM to allow administrators to monitor the deployed VM, but also to design education-oriented monitoring dashboards intended for learners and teachers.

We integrated, into each virtual machine, two different agents (i.e. MIB-II SNMP and WBEM-SBLIM ProviderCmpiBase) collecting the same metrics in order to go beyond potential failures of one of the two agents. In this case study, we assumed the following service level agreement: (i) the various metrics must be pushed by agents each 10 seconds to a local self-adaptive manager embedded into the virtual machine; (ii) two time-slots have to be addressed: metrics must be delivered to client applications (e.g. the management application, the tutoring dashboards) with a freshness falling into a timeframe of [3-6] seconds during daylight hours, whereas they must be delivered each 30 to 40 seconds during night hours; (iii) metrics values must be instrumented through polling mechanisms, and delivered to clients through export mechanisms; (iv) the self-adaptive managers poll the instrumented metrics each 3 seconds.

From this service level agreement, we defined three high-level quality objectives related to the monitoring itself. "Respect of Metrics Delivery Freshness" makes sure that metrics are delivered to clients at the right frequency. "Minimise Monitoring Cost" aims at minimising the number of resources dedicated to monitoring. "React to Gathering Problems" operates resilient gathering mechanisms while inspecting the potential reasons of gathering failures.

Objectives refinement. The refinement tree of the first objective is illustrated in Figure 2.10. During the first time-slot, if the self-adaptive managers deliver metrics at the highest freshness level (i.e. 6 seconds), the temporal pattern can be reused to decrease the frequency of the polling and exporting mechanisms by updating their periods (see the refinement of the *Acting on temporal dimension* goal). If the frequency of the metrics delivery exceeds the highest freshness level, the faulty manager might be overloaded and two patterns can be reused. The spatial pattern may be applied to make the overloaded manager delegate a part of its managed

perimeter to a new manager (see the refinement of the *Acting on spatial dimension* goal). As an alternative, the knowledge pattern can be reused to assign to an existing manager some of the metrics instrumented by the overloaded manager (see the refinement of the *Acting on knowledge dimension* goal). Also, during the time-frame of the second time-slot, agents push metrics each 10 seconds whereas they have to be delivered to client applications each [30-40] seconds only. In that case, there is no need for managers to poll/export all metrics. The knowledge pattern can be used again to create an aggregated metric containing the last three values of the SLA metric, and combined with the exchange pattern to deactivate the polling mechanisms and update the exporting period (see the refinement of the *Acting on knowledge and exchange dimensions* goal).

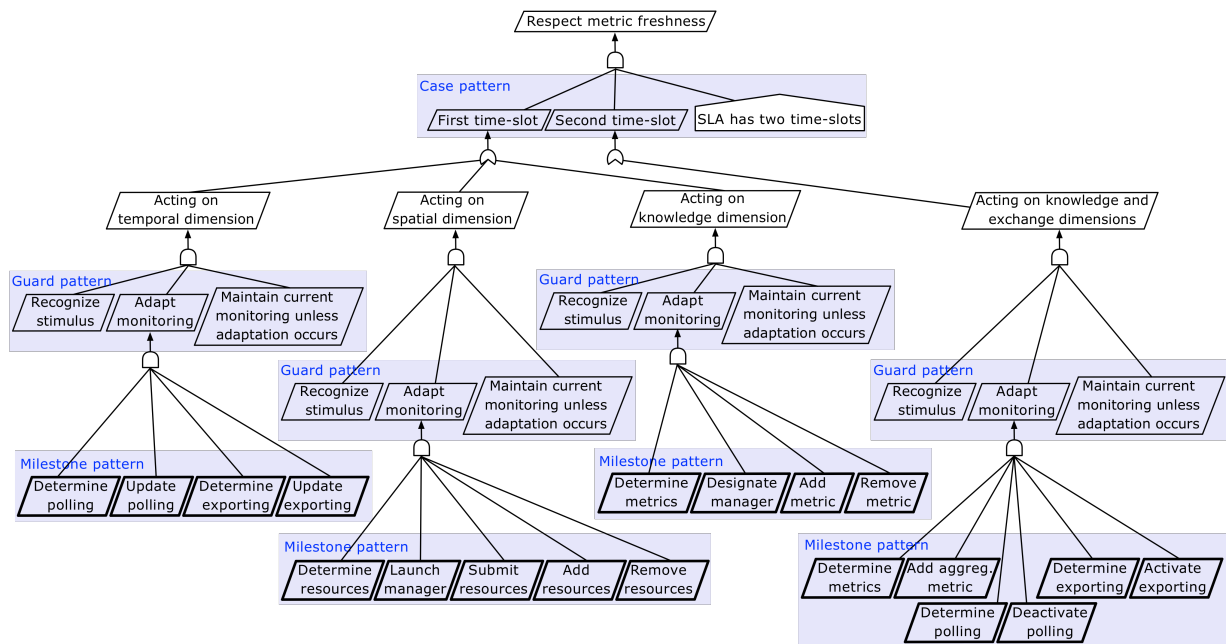


Figure 2.10. Refinement tree of the first objective.

The refinement tree of the second objective is illustrated in Figure 2.11a. Considering that the monitoring load increases during daylight hours, and that several self-adaptive managers have been launched to keep the previous objective satisfied, the spatial pattern can be reused during night hours. The underloaded managers have to delegate their whole set of managed resources to one of their peers before shutting down.

Finally, the exchange pattern can be reused during both time-slots to address the third objective. We reused some modification actions of the pull communication mode between a manager and an agent (see Figure 2.9) to design the refinement tree of Figure 2.11b. However, as our prototype did not support several protocols to communicate with a single agent, the requirements related to protocol adaptation have not been implemented.

Instrumentation of the quality-driven adaptation. Our self-adaptive monitoring system built on a model-driven platform developed by our research team and providing adaptive capabilities (Moui et al., 2012a). The framework, based on the WBEM architecture (DMTF,

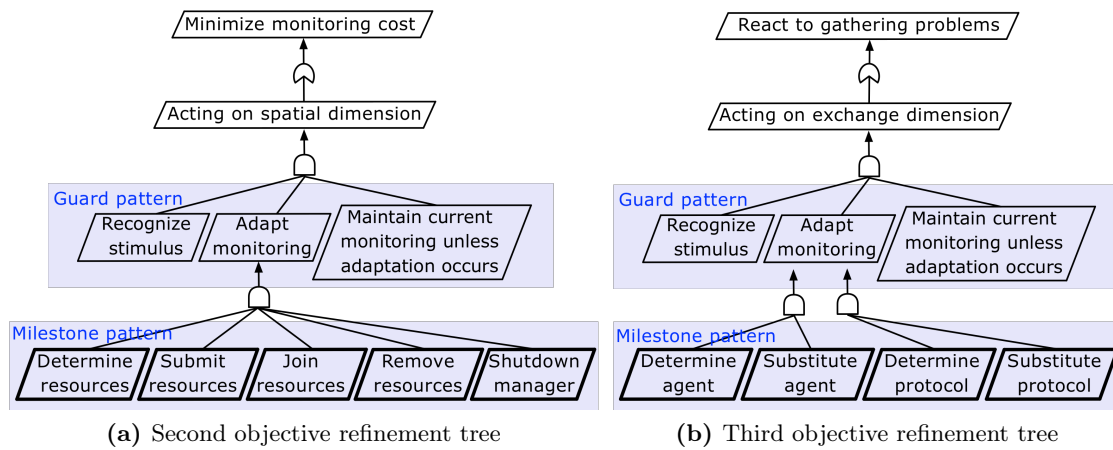


Figure 2.11. Refinement trees of the second and third objectives.

2012), is illustrated in Figure 2.12. It implemented OpenPegasus⁸, the C++ Open Group⁹ instrumentation of the DMTF standards.

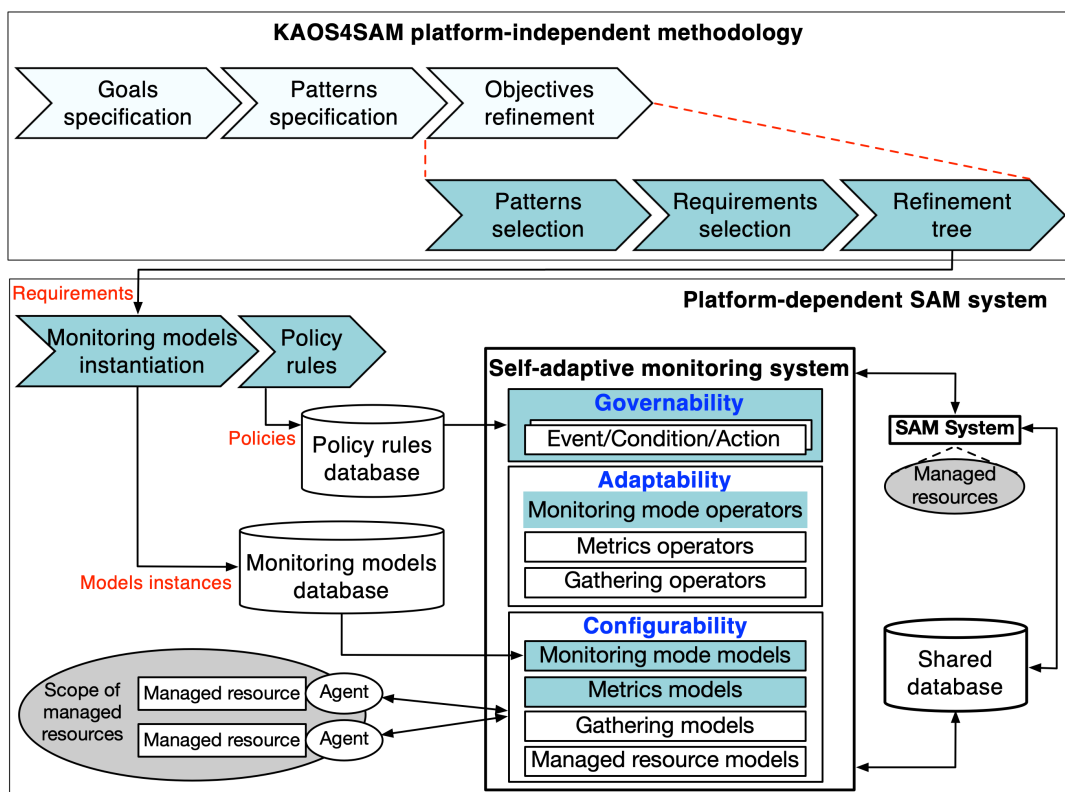


Figure 2.12. From KAOS4SAM to the self-adaptive monitoring system.

⁸<https://collaboration.opengroup.org/pegasus/>

⁹<http://www.opengroup.org/>

The configurability layer hosts models representing, in addition to the resources to be managed, the metrics (Toueir et al., 2011) and exchange mechanisms (Moui et al., 2012b) required to monitor both the virtual machines of the cloud provider, and the quality of the monitoring system. In addition to the metrics models, our contributions were related to the models of monitoring mode we introduced. These models act as containers encapsulating coherent monitoring configurations so they can be applied as a whole to ensure adaptation consistency. Basically, a monitoring mode encapsulates the metrics to instrument, the constraints to assess, and the filters and destinations of the raised indications. For the case study, we instantiated one monitoring mode model for each *Acting on* branch of the refinement trees (see Figures 2.10 and 2.11), and specified new algorithms to create, remove, activate and deactivate a monitoring mode.

The adaptability layer was responsible for providing, as a Java SBLIM API¹⁰, a control interface encapsulating operators driving the execution of the monitoring mechanisms. Using these operators, the behaviour of the monitoring was reconfigured at runtime through the creation, deletion and update of instances of exchange services and metrics, and the underlying polling and exporting mechanisms could thus be started, stopped, suspended or resumed. In this layer, we developed new operators handling the algorithms related to the monitoring mode models.

Finally, the governability layer implemented the Ponder2 system¹¹ and used the PonderTalk language to express Event/Condition/Action policies describing when and how adaptation actions should occur, that is when and how operators of the adaptability layer should be invoked. For each set of requirements identified in the refinement trees, we designed the matching policy rule. The Java method invoked when the monitoring self-adapts according to the spatial dimension of the first objective can be found in (Toueir, 2014).

Results. Through this case study, we demonstrated how the patterns of Section 2.3.2.3 can be reused to refine specific high-level quality objectives. Table 2.2 gives quantitative data regarding the requirements and the matching computing methods needed for completing the three quality objectives. Among the 30 requirements, only two of them have been explicitly designed for the purpose of the case study. One specific requirement (i.e. "Shutdown manager" of the spatial pattern) allowed to reduce the number of collaborative managers, whereas the other (i.e. "Designate manager" of the knowledge pattern) was required to satisfy the first objective but missing from the pattern. Through this case study, we also showed how a quality-driven adaptation could be integrated into an existing monitoring system by extending the self-adaptive monitoring system by Moui (2013). Among the set of methods required to execute the adaptation actions allowing to achieve the objectives, only 20% of them had to be freshly implemented.

2.3.2.5 Discussion and positioning of the works

We could not find prior works proposing an adaptation of monitoring based on high-level quality objectives about the monitoring itself. Therefore, in this section, we align our proposals with other existing approaches focusing on monitoring of quality of service (QoS) in autonomous systems, or design of patterns addressing deployment and adaptation of monitoring modules.

In many cases, when monitoring detects QoS degradation, the autonomous system adapts services of the functional system rather than the monitoring itself. Most of current initiatives,

¹⁰http://sblim.sourceforge.net/wiki/index.php/Main_Page

¹¹<http://ponder2.net/>

Table 2.2. Quantitative data about the case study.

Objective	Dimension	Case study requirements		Computing methods	
		From patterns	New	From platform	New
Respect of metrics delivery freshness	Temporal	4	0	1	0
	Spatial	5	0	5	0
	Knowledge	4	1	3	1
	Knowledge and exchange	6	0	2	1
Minimize monitoring cost	Spatial	5	1	4	2
React to gathering problems	Exchange	4	0	1	0
	Total	28	2	16	4

including the FoSII project investigating self-agreement of SLA in cloud computing infrastructures (Anithakumari and Sekaran, 2014), perform reconfiguration of resource allocation (Katsaros et al., 2012), redirection of client requests (Mezghani et al., 2014), or replacement of service providers (Zhai et al., 2009). This type of adaptation increases quality of the functional system, but also prevents the monitoring system to be provided with data describing the degrading situation and to handle new failing and unexpected contexts. Monitoring more metrics or managed resources is another approach to adapt monitoring to: meet SLA (Roxburgh et al., 2011) and policy (Ouda et al., 2010) modifications; deal with changes of the managed resources scope (Grefen et al., 2000); or operate a "minimal" monitoring (Munawar et al., 2008). Even if scaling up and down the monitored metrics and resources is important, it is not clear whether the above proposals could apply to other scenarios for other objectives and, if so, how that could be feasible.

Deployment and reconfiguration of monitoring resources have been addressed for a number of purposes: increase of metrics precision (Liakopoulos et al., 2010); integration of monitoring into the SLA lifecycle (Roxburgh et al., 2011); optimisation of the monitoring performance according to the user context (Contreras et al., 2012); replacement of faulty managers (Thongtra and Aagesen, 2010); monitoring of particular paths or segments (Nobre et al., 2012). Apart from the clear benefits of deploying monitoring resources at runtime, it is difficult to figure out how administrators can orchestrate the monitoring adaptation among several collaborative managers.

Finally, inspired by the IBM reference architecture (2005), patterns regarding the distribution of the adaptation modules were proposed in (Weyns et al., 2013). Those patterns are useful in terms of reuse and elicitation of the application contexts, but they mainly address the operational deployment of the monitoring modules rather than the behavioural facet of the monitoring.

2.4 Conclusions

The main objective of this chapter was twofold: (1) to propose solutions to federate a wide range of attention metadata, and (2) to ensure a quality-oriented management of these data.

Our main contributions to federate heterogeneous attention metadata relate to a unifying user learning experience model supported by a privacy-aware architecture. The model is a compromise between completeness, flexibility and usability. It offers an extensible core backbone that may serve as a basis for tracking user experiences within different situations (Broisin et al., 2011; Broisin and Vidal, 2017), and features the definition, processing and reuse of indicators inferred from the collected data. The supporting architecture we designed splits sensitive and non sensitive data into different storage locations to preserve user privacy. To ensure quality of knowledge, we adopted a self-adaptive monitoring approach and designed a goal-oriented methodology that helps human administrators orchestrate adaptation of monitoring. The originality of the methodology is twofold: it drives adaptation strategies according to high-level objectives related to the quality of monitoring, and ensures a vertical consistency between the high-level quality objectives and the low-level configurations of monitoring components. Also, we designed a set of patterns identifying fine-grained adaptation actions that may serve as a reference repository to assist administrators to guarantee the quality of service provided by the monitoring itself.

One limitation of our model lies on the vocabulary to be used to express user learning experience. For instance, one might say "Jack played the last 60 seconds of the video entitled Python for beginners", whereas another might say "Jack watched from 9'50" to 10'50" of the video entitled Python for beginners". In that case, two different activities characterised by different properties should be specified, even if they have the same meaning. ADL, which faces the same issue with the xAPI initiative, expects communities of practice to define *recipes* specifying the vocabulary to be used in their profiles. As far as we know, only a few recipes about assessment, attendance, bookmarklet, video interaction, open badges and self-regulated learning emerged for the last seven years. Concretely, this results in specific and ad-hoc data structures and vocabularies, as researchers even ignore the recipe concept (Goodwin et al., 2016). The effort of ADL to provide predefined and controlled vocabulary for verbs and activities¹² currently represents the best alternative to use a common terminology for describing user learning experience.

Another limitation of our works lies on the architecture. To ensure privacy of users, we suggested to store learners' personal information into their own device. This approach allows for automatic adaptation, as access of users to adaptive systems provide them with the full profile of users. Regarding manual adaptation, our approach introduces a restriction. Because they provide their personal information to the system, learners can self-regulate their learning according to the information exposed by the system. However, teachers are provided with anonymous learners profiles. They can apply a given adaptation strategy to a specific user through the system, but they are not able to make face-to-face individual interventions.

Regarding the implications of these works, our proposals for user learning experience modelling made us participate in the work package 8 of the Open Discovery Space project. We contributed to design and deploy a social data infrastructure to aggregate, store, process and expose social and usage data related to learning resources. This social data management layer represented the basis for stimulating finding, reuse, repurposing and sharing of learning resources, but also for enhancing and deploying advanced social navigation and visualisation services intended to enrich and empower learning portals. Also, the goal-oriented methodology we defined to design a self-adaptive monitoring system could be reused to satisfy other types of quality of service in other adaptation contexts. Especially, it could be used to drive adaptation of learning

¹²<http://xapi.vocab.pub/browse/>

systems according to high-level personalisation objectives. Patterns matching with the main categories of adaptation could be specified to identify their respective high-level objectives, goals and matching requirements. Research on adaptation and personalisation is abundant, and running a systematic literature review could help to design patterns covering a large panel of adaptation practices. These patterns would provide guidelines and good practices to pedagogical engineers and designers who aim to build adaptive learning systems.

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Chapter 3

Formative assessment and inquiry-based learning to foster active learning

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3.1 Introduction

In 2009, the UNESCO Institute of Statistics emphasised, in its global education digest ([UNESCO, 2009b](#)), a very substantial increase in the number of students registered in higher education. At the international level, higher education population is twice bigger every fifteen years, and this expansion is especially strong since the early 2000s. Between the years 2000 and 2007, 51.7 millions of new students have registered for a university programme. The same institute highlighted a strong growth of the number of primary and secondary school learners as well ([UNESCO, 2011](#)). Secondary school population in North America and Europe was near 220 millions in 2000, and jumped to 300 millions in 2009 (i.e. a raise of 36%).

Higher education institutions have to support this significant development to ensure good academic results, but also adapt to the new requirements of the new society. To deal with these challenges, most international countries have proposed specific measures and policies dedicated to education (Chevaillier, 2014). For example, in France, the government supported a five-year plan to lead 50% of students to the bachelor level, by putting around 730 millions of euros in hands of universities. The expected results were far from being achieved, as only 27% of students have completed their degree at the end of the normal three-year period (MENESR, 2014). Such experiences raise the question of the financial and human resources, and UNESCO even wonders about the capacity of governments to support the growing demand for education (UNESCO, 2009b). Also, the economic and health contexts give no reason to believe that resources dedicated to HEI will follow the curve of the education population growth. Obviously, HEIs have to adapt to these constraints by means of sustainable and scalable quality strategies.

Our approach to introduce new innovative strategies into universities was based on student-centred learning theories, and more precisely on active learning. The term *active* denotes "*any instructional method that engages students in the learning process*" (Prince, 2004, p. 223) and encompasses both peer-assisted and inquiry-based learning approaches. As many definitions of engagement exist, we adopted the definition by Baron and Corbin (2012, p. 763): "*the engaged student is the student who has a positive, fulfilling and work-related state of mind that is characterised by vigour, dedication and absorption and who views him or herself as belonging to, and an active participant in, his or her learning communities*". The works presented in this chapter especially focus on how we exploited technology-enhanced learning to design interactivity-rich instructional environments that: comply with constructivist theories of learning to foster active learning; evaluate hypothesis and proposals within authentic contexts; promote intentional learning; support student progress through assessment tasks.

Our research thus relied on design and development of learning systems. Engineering of learning systems that tackle specific issues in particular contexts serves as a basis to discover and build new knowledge (Tchounikine, 2009). Our goal was to elaborate innovative and interactive learning processes, and to design and experiment new environments for investigating the impact of rich interactive artefacts on students' engagement and performance.

3.2 Research context and questions

Our efforts to develop sustainable strategies focused on two main objectives: (1) to increase interactivity and learners' engagement in large scale educational settings, and (2) to offer learners the opportunity to put knowledge into practice through real-world problems.

Lectures represent a crucial piece of the learning process, as they are one of the places where students acquire theoretical concepts and knowledge. Even if Bloom (1984) showed that one-to-one tutoring leads to highly superior learning outcomes than group instruction, the latter remains widely used in higher education institutions because it represents one of the less expensive strategies, and thus one of the most sustainable programme at a large scale. The traditional form of lectures (i.e. a lecturer delivering information using whiteboards and/or digital resources) suffers from a number of well-known weaknesses: the passive role of students, the lack of interactivity, the difficulty of leading to a personal approach, the impossibility to take into account students' diversity, and the difficulty for students to pay attention during the whole session. Therefore, the

questions of the evolution of group instruction as well as its adaptation to nowadays students' profiles were in the focus of our research.

Practical activities are of most importance in STEM education, as they help students develop professional and inquiry competences, group work and communication skills. They are efficient to develop inquiry-based learning. However, even if universities deliver practical activities to students, practical sessions are difficult to maintain as the number of students increases. Also, engineering programmes are tightly packed, thus making it difficult to leverage classrooms dedicated to these activities. In addition, the setting up of laboratories may rapidly become very expensive in terms of equipments, rooms, and staff members. Investigations about low cost solutions mirroring hands-on laboratories that allow students to carry out practical activities anywhere, represented the other line of research we studied.

3.2.1 Interactive large scale formative assessment

Many studies demonstrated the ability of electronic voting systems, also known as audience response systems (ARS) or simply clickers, to stimulate learners in large group instruction. They increase learners' engagement (Uhari et al., 2003; Blasco-Arcas et al., 2013), create a more positive and active atmosphere (Caldwell, 2007), and offer teachers opportunities to drive constructive discussions (Gauci et al., 2009). Such systems allow students to answer multiple-choice questions asked by instructor and displayed on a screen. Students' answers are collected in real time, and the matching anonymised results are available to the audience once each student gave her response. Clickers thus represent a mean to introduce formative assessments in lectures (Kay and LeSage, 2009) and to provide students with feedback allowing them to know where they stand. However, formative assessment sessions instrumented through clickers lack interactivity at different levels. First, there is little interaction between students as they answer individually to questions. Second, clickers often feature numeric buttons only that restrict feedback delivered to students to statistical indicators, even if prior research showed that the quality of feedback provided to learners is a key factor for better learning (Black and Wiliam, 1998; Higgins, 2000).

Our approach to increase interactivity between students during formative assessment sessions consisted in adopting a peer instruction teaching method. Especially, we based our proposals on the Think-Pair-Share strategy (TPS). This strategy promotes learners' engagement in learning activities when used with small groups of learners. In the context of large group instruction, several problems emerge: How to share ideas between students when the settings of the classroom make it impossible to set up small working groups? How to make possible sharing of answers results with all students? To face these problems, we adopted the Bring Your Own Device approach which offers students the opportunity of using their smartphone, tablet or laptop to engage in TEL systems and activities. Our objective was to investigate how technology could be used to implement the Think-Pair-Share strategy at a large scale. Therefore, we tackled the following research questions already given in the introduction chapter:

RQ 1: How to adapt the Think-Pair-Share strategy to massive learning settings?

RQ 2: How to implement the matching process into a formative assessment tool?

The methodology we adopted to tackle these questions relied on the peer assessment strategy and consisted in the following steps: (i) the specification of a new educational process implement-

ing a TPS-oriented strategy in the context of formative assessment; (ii) the design and deployment of a system implementing the strategy and process; (iii) the setting up of experiments in authentic contexts to evaluate engagement of students.

3.2.2 Remote and virtual laboratories

Practical activities, referred to as "any learning and teaching activity that engages learners in manipulating and analysing real and physical objects" in this document, are efficient when learners come to acquire inquiry skills (de Jong et al., 2013). In STEM, inquiry-based learning is a pedagogical method relying on constructivist and socio-constructivist theories of learning that allows students to learn about science by engaging them in investigation (Bell et al., 2010). Learners build their own interpretations of scientific concepts and acquire knowledge about how to do science through realistic works.

Our research focused on practical activities mediated by virtual and remote laboratories (VRL, or simply remote lab). These activities bring a number of advantages (Lowe et al., 2013): they can be used by a large pool of students distributed in multiple institutions (Orduña et al., 2012); they provide students with access to a wide range of equipments anytime, anywhere (Lowe et al., 2009a; DeLong et al., 2010; Leproux et al., 2013); and students gain longer interaction time with these equipments. Also, remote labs capture a large amount of data that can be analysed to support students in their learning process. For example, results obtained by previous students can be reused as a starting hypothesis for the subsequent ones, while all data and conclusions can be available to all students. In the remainder of the manuscript, remote practical activities refer to traditional practical activities extended and modified to be accessible online by anyone, at anytime, from any device connected to the Internet.

The "first generation" of remote laboratories focused primarily on hard computing issues, and provided strong solutions to complex problems. Prior research has made remote labs scalable in terms of amount of students and equipments that can be manipulated, but several large-scale studies showed that instructional supports during practical activities are almost as important as technical features. Corter et al. (2011, p. 2056) highlighted that "*the scaffolding around the lab may be at least as important as the lab itself*". Also, a survey conducted in different Australian states (Kostulski and Murray, 2011, p. 209) showed that students were missing "*help and support*" and "*engagement in the experiment*" during remote lab sessions. This result is very much inline with the "*opinions of a large number of academics who had also identified engagement as an area where remote labs need to evolve further*" (Kostulski and Murray, 2011, p. 209).

Our works thus mainly focused on the educational aspects of remote labs and investigated the following research questions (see the introduction chapter):

RQ 3: How to design an engaging remote laboratory environment?

RQ 4: How to promote social interactions in remote laboratories?

RQ 5: How to instrument collective forms of learning into remote laboratories?

We explored the above questions in the context of computer education with university students. We adopted a methodology consisting in: (i) designing a remote laboratory environment

standing on existing virtualisation technologies so as to benefit from their advanced and scalable computational features; (ii) designing and integrating original scaffolding tools and services into this system; (iii) setting up experiments in authentic learning contexts; (iv) evaluating the effectiveness of the system in terms of learners' engagement and academic performance.

3.3 Contributions

3.3.1 Instrumentation of an innovative formative assessment process: Tsaap-Notes

The objective of the work exposed in this section was to design interactivity-rich solutions promoting students' engagement in formative assessment activities. Our research to tackle RQ1 and RQ2 has been mainly developed during Franck Silvestre's Ph.D. thesis (2015), and resulted in the specification of a TPS-oriented process adapted to large instruction settings, the design of an algorithm promoting peer instruction and assessment, and the development, experiment and evaluation of a system implementing the proposed process and algorithm.

3.3.1.1 Specification of a TPS-oriented process

We designed a TPS-oriented process on the basis of the formative assessment theoretical framework by Black and Wiliam (2009). These authors investigated how to unify the diversity of theories, practices and experimental results fostering quality of formative assessment. Specifically, these authors defined a set of high level pedagogical strategies: (S1) to clarify and share learning intentions as well as criteria of success; (S2.1) to design situations allowing for effective classroom discussions, and (S2.2) to design learning tasks that elicit the progress of learners in their understanding; (S3) to provide learners with feedback that makes them move forward; (S4) to make learners become instructional resources for peers; (S5) to make learners responsible for their own learning. The framework established five activities to foster these strategies: (A1) sharing criteria of success with learners; (A2) questioning the classroom; (A3) use of comments rather than numerical grades to assess learners; (A4) self- and peer assessment; (A5) formative use of summative tests. Each activity A_i develops the strategy S_i , but activity A5 that addresses the strategies S1, S2 and S3; also, in addition to strategy S4, activity A4 focuses on strategy S5.

Our TPS-oriented process (Silvestre et al., 2017) breaks the formative assessment sequence into several distinct steps, or phases, during which one or several strategies are used. The process of Figure 3.1 comprises four distinct phases. The first phase of the process matches with the first phase of the Think-Pair-Share strategy. Teacher asks a question to the classroom, and students submit individually their response. To increase interactivity and foster reflection, this phase also asks students to justify their answer; in addition, students are asked to provide their level of confidence about their answer. The second phase represents a key step of our process. In the traditional TPS strategy, this phase suggests small group discussions so that each group of students proposes a collective answer. To make learners think about their own knowledge in the context of large group instruction, we also adopted a peer instruction approach to explicitly generate socio-cognitive conflicts. Each student is provided with a textual feedback matching with an alternative answer and its justification submitted by a peer. Students are invited to engage in

the socio-cognitive conflict by thinking about their answer against peer's answer, and have the opportunity to submit a different answer or to confirm their initial response. The third phase of the process, like in the TPS strategy, is dedicated to delivery of feedback to students. General statistical data about answers of the whole classroom are delivered to students, and text-based feedback is also provided by asking learners to evaluate a maximum of three rationales matching with the right answer. The originality of this approach is twofold: it integrates the peer assessment activity, and brings a solution to the immediate evaluation of textual answers. Finally, at the end of the peer assessment task, details about the percentage of right and wrong answers, together with the best rated rationales, are displayed by the lecturer in the classroom. Lecturer then acts as a facilitator during the fourth phase and drives oral discussions about the question and the best rationales matching with the right answer. Students are encouraged to discuss, take notes and engage in the deep learning process.

3.3.1.2 Algorithm for socio-cognitive conflicts

The socio-cognitive conflict is generated by assigning students, at the beginning of phase 2, an answer and rationale different from the response they submitted. Our algorithm responsible for this process is described in details in (Silvestre et al., 2015c). It comprises two main steps.

The first step takes all answers and rationales as inputs, and builds two disjointed sets of answers: the list of right answers and the list of wrong answers. For each list, the algorithm removes the answers that can not be used for socio-cognitive conflicts. Such answers are those whose length of the associated rationale is below a given threshold. The algorithm then sorts the lists of eligible answers according to the associated degree of confidence mentioned by student, and to the length of the rationale. The higher the confidence level of the answer, the higher it appears in the list. When two answers have the same level of confidence, the answer ranked in the highest position of the list is the one with the largest number of characters in the rationale.

The second step consists in associating a conflict-eligible right (respectively wrong) answer to each wrong (respectively right) answer. Here we defined a function that associates items of a conflict-eligible sorted list of answers, to items of a set of answers. This function is based on a round-robin scheduling algorithm where items of the conflict list are circularly assigned to items of the set of answers. When the size of the conflict list is lower than the size of the set of answers, some items of the conflict list are assigned to several items of the set of answers.

3.3.1.3 Design of the formative assessment system

The formative assessment system we designed to support the above process and algorithm is based on web technologies and has been developed with the Java EE environment according to the model-view-controller design pattern. Let us note that transitions between two steps of the process are manually handled by the lecturer based on her appreciation.

The first phase in Tsaap-Notes is implemented as a form allowing participants to (i) answer the question asked by the teacher, (ii) give a text-based rationale about their choice, and (iii) indicate their degree of confidence regarding their answer through a five-level Likert scale.

The graphical user interface triggering the socio-cognitive conflict is illustrated in Figure 3.2. The bottom part of this figure shows the form of phase 1. The top part of the figure provides

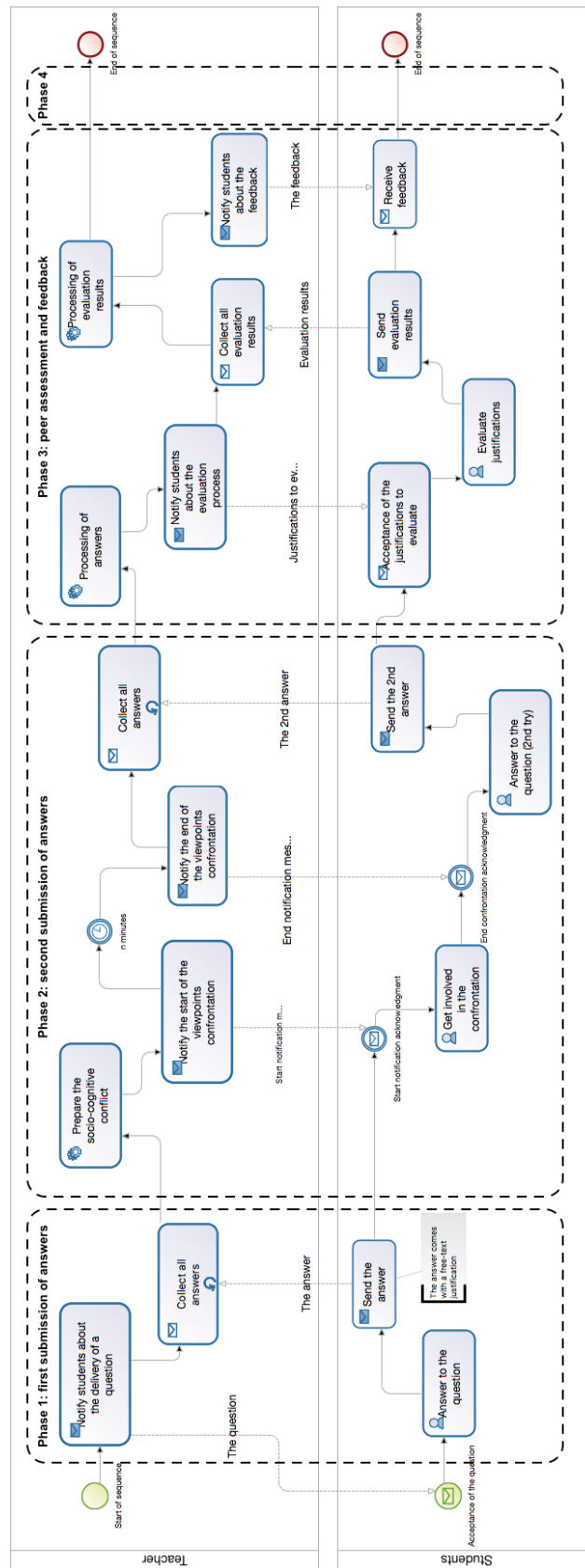


Figure 3.1. BPMN modelling of the TPS-oriented process.

students with an alternative answer submitted by a peer, together with the matching rationale. Let us note that no information about the author's identity of the alternative answer is exposed within the user interface, so as to avoid any relational influence. The name of the user appearing at the top-left corner of Figure 3.2 is the name of the user currently logged in Tsaap-Notes.

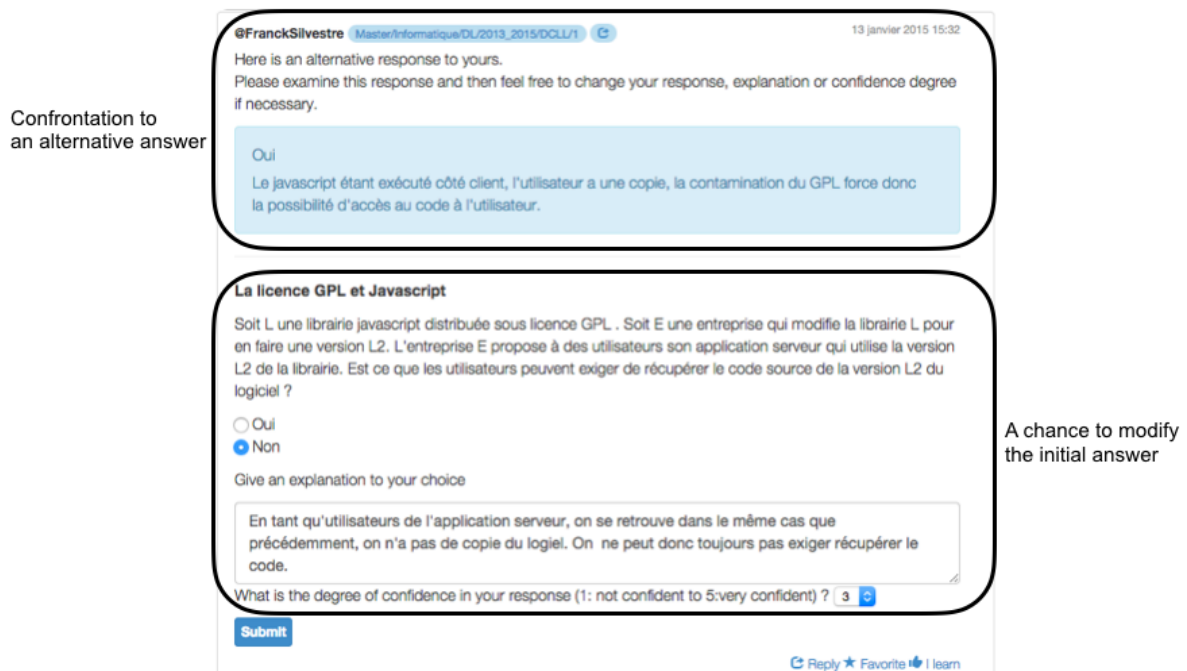


Figure 3.2. The TPS-oriented process in Tsaap-Notes: phase 2.

Once all participants have validated their second answer, general results are displayed to students as illustrated in Figure 3.3. Learners get aware of their score regarding the question, and they are able to position themselves in relation to the mean score of the whole set of participants. Also, the peer assessment activity is triggered in this phase as learners are invited to assess, using a five-level Likert scale, three distinct rationales that all match with the right answer. The algorithm assigning rationales to learners is also based on the round-robin approach and associates each good answer to three students. Once the peer assessment activity is over, Tsaap-Notes computes the average rate for each explanation, builds a list sorted in descending order, and exposes to participants a form including the best rated explanations. The final phase of the process is then launched by the teacher, and students can initiate and engage in discussions.

In addition to the TPS-oriented process, we integrated into Tsaap-Notes a feature offering instructors the opportunity to export questions related to a given course towards a *de facto* standard for electronic quizzes (i.e. the General Import Format Technology format). They can thus easily create computer-based self-assessment tests that can be replayed an unlimited number of times by students within institutional virtual learning environments (Silvestre et al., 2014a). The originality of our approach resides in the reuse of the best-rated rationales provided by learners during the lecture, as feedback for the questions within the online tests (Silvestre et al., 2015a). When accessing and running tests through the VLE, learners get richer feedback, including both numerical score and text-based explanations written by peers.

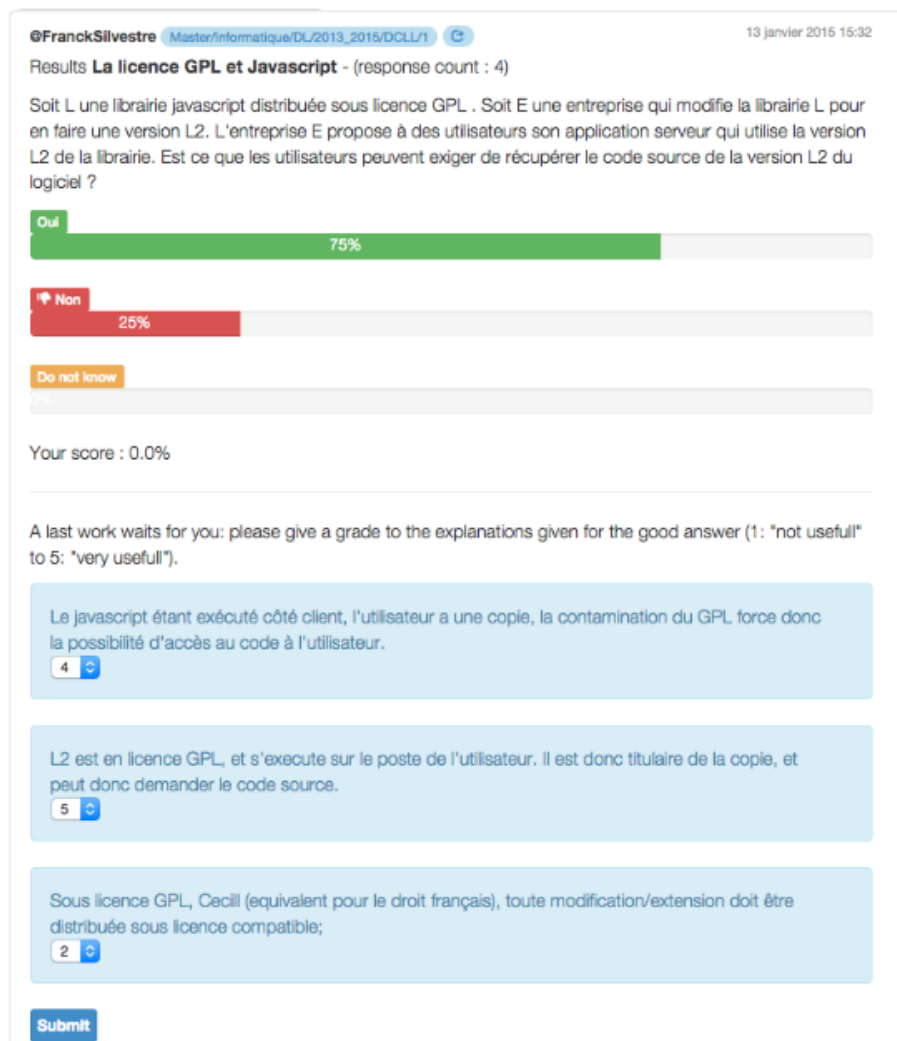


Figure 3.3. The TPS-oriented process in Tsaap-Notes: phase 3.

3.3.1.4 Experiments and results

Tsaap-Notes has been experimented with two groups of students in two courses integrated in the first year of a Computer Science Master programme (Silvestre et al., 2015b). The experiment took place during 3 sessions of 2 hours during which 5 questions were asked to students. The objectives were to validate the three following hypothesis: (H1) the socio-cognitive conflict has a positive impact on learners' engagement in writing rationales; (H2) peer instruction positively impacts the rate of right answers submitted at phase 2 of the process; (H3) reuse of quality explanations as feedback in online tests engages learners in the peer assessment activity.

Results of these experiments were encouraging. In average, almost 88% of students submitted an answer to each question. This high participation rate is in line with other research study outcomes about audience response systems (Hunsu et al., 2016). A more interesting result is the participation rate of students in the submission of a rationale for their answer. Statistical analysis showed that 68.29% of students that answered a question also submitted an explanation

to justify their answer. In addition, quality of students' productions was highly influenced by the socio-cognitive conflict: whereas a previous study showed that only 5.7% of the rationales could be reused as feedback in online tests (Silvestre et al., 2014b), this rate went up by a factor of 10 (i.e. 57.39%) with the introduction of the second phase of the TPS-oriented process.

Results also showed that 30% of students that gave a wrong answer on the first attempt altered their answer for the second submission phase towards the right answer. These students fully benefited from peers' productions where the alternative answer made them think about their own knowledge. This study result is in line with other research findings regarding the peer instruction approach (Crouch and Mazur, 2001).

Finally, we noticed that 75.6% of students participated in the peer assessment process that consisted in rating three rationales written by peers. This high level of engagement might be explained by the fact that peer assessment of explanations increases quality of feedback included into the computer-based self-assessment tests that can be automatically generated by Tsaap-Notes, as they include the best rated contributions only. Indeed, another experiment conducted in (Silvestre et al., 2015a) showed that only 7% of students ran a test without text-based feedback, whereas 87% of them ran at least once the test providing students explanations as feedback.

At the end of the experiment, students were asked to evaluate Tsaap-Notes in terms of usability. Among the 85 students involved in this study, 43 of them filled in the system usability scale (SUS) questionnaire (Brooke, 2013). The score given to Tsaap-Notes was 77.8, thus making it a "good" system according to Bangor et al. (2009).

3.3.1.5 Discussion and positioning of the works

The TEL environment we designed to implement a TPS-oriented process in large group settings brings a number of valuable innovations when compared to traditional audience response systems (Uhari et al., 2003; Elliott, 2003; Cutts, 2006) or more advanced approaches (Burnstein and Lederman, 2001; Draper and Brown, 2004; Cline, 2006; Trees and Jackson, 2007; Beatty and Gerace, 2009). In our proposal, the peer assessment task (i.e. activity A4) adds a third phase devoted to the evaluation by learners of peers' contributions matching with the right answer. During this phase, students are fully engaged in the peer instruction approach and benefit from understandings of their peers (i.e. strategy S4). Also, the socio-cognitive conflict occurring during phase 2 makes learners think about their own knowledge (i.e. strategy S5), but also sets up excellent conditions fostering students to engage in the discussion process (i.e. strategy S2.1). Finally, richer feedbacks are delivered to learners at different times of the process, including both textual elements during the second phase, and numerical values at the end of phase 3.

Several initiatives enhanced traditional audience response systems (Yamamoto et al., 2014; McLoone et al., 2015). A system very similar to Tsaap-Notes has been developed by Charles et al. (2014a,b). It is called DALITE (Distributed Active Learning Technology Integrated Environment) and organises the formative assessment tasks into several phases. During the first two phases of the process, students select a multiple choice answer to a question, and justify their answer. During phases 3 and 4, other rationales of the selected answer but also rationales of alternative answers are delivered to students; one of these two groups of rationales always matches with the right answer. In phase 5, students vote for the most convincing rationale and finally, they are provided with feedback exposing their answers and an expert rationale.

The main difference between Tsaap-Notes and DALITE is that the latter has been originally designed for asynchronous peer instruction (Bhatnagar et al., 2015), i.e. for use outside the classroom in distant and/or blended learning contexts such as MOOCs (Bhatnagar et al., 2016) or flipped classroom (Charles et al., 2019). As a consequence, the system automatically triggers transitions between two steps of the process, and learners are able to follow the whole process in-a-row, independently of what peers are doing. At the opposite, transitions are manually triggered by lecturers with Tsaap-Notes, and learners synchronously follow the same phase of the process. The DALITE asynchronous approach inspired Parmentier and Silvestre (2019) to integrate into Tsaap-Notes a similar script allowing students to carry out formative assessments in online and/or blended settings. On the other hand, myDALITE extended DALITE to be used inside the classroom, i.e. in a synchronous manner (Charles et al., 2019). Concerning communication of results to students, DALITE exposes histograms and an expert rationale, whereas feedback provided by Tsaap-Notes comprises numeric data and the best rated rationales. From the teacher perspective, DALITE offers more advanced features such as a dashboard including, for each question and each student, all answers that have been provided as well as the associated rationale (Charles et al., 2014a). It also provides a teacher gradebook exposing statistical information about the number of student responses, the number of wrong to right transitions, etc. (Charles et al., 2019). Finally, compared to Tsaap-Notes, DALITE features a more advanced approach to filter the alternative rationales delivered to students, as a filtering approach based on text classification techniques (i.e. bag of words and vector space models) allows to detect irrelevant and inappropriate answer rationales (Gagnon et al., 2019).

Features integrated into our formative assessment platform, such as the export mechanism of questions towards quizzes that can be played by learning systems such as Moodle, provides clear learning benefits: feedback gets more chance to be understood by learners, because it comes from their productions and is written in their own dialect (Chanock, 2000; Higgins, 2000); different lectures delivered to different groups will produce different feedback to the students of each group, thus increasing its quality (Bull and McKenna, 2003). However, further improvements have to be addressed regarding the feedback quality and consistency. Irrelevant explanations that are highly evaluated by students often lead to constructive discussions, however they may appear in online tests and lead to misunderstandings or misconceptions. Our process should be extended to explicitly include a verification phase once the discussion is over to discredit the best rated but inappropriate contributions. Finally, the nature of the questions asked to students is another important point to discuss. Questions must refer to general understandings or conceptual ideas, and have to be designed to assess comprehension. Based on the revised version of Bloom’s taxonomy (Bloom et al., 1994), effective questions in our context should require students understanding, applying and analysing their knowledge. Some research lines regarding this topic are proposed in the last chapter.

3.3.2 Education-oriented cloud for computer education: Lab4CE

The overall objective of our research about remote laboratories was to propose innovative solutions fostering remote practical activities in the context of computer education. These works have been initiated during Amine Bouabid’s Ph.D. thesis in which we investigated how to provide learners with their personal remote lab (Bouabid, 2012). They have been further developed during Rémi Venant’s Ph.D. thesis by focusing on learning analytics to promote learners’ engage-

ment in inquiry-based learning (Venant, 2017). Starting from a widely adopted architecture for virtual remote laboratory, we addressed RQ3, RQ4 and RQ5 and contributed to a fine-grained management of the VRLs provided to users, a learning analytics framework allowing for innovative scaffoldings around the lab, and rich user interfaces offering interactive features. Before exposing these contributions, we give below the requirements that drove our works.

We identified in (Broisin et al., 2017b) some pedagogical capabilities required to enhance existing VRL initiatives. The remote lab environment should provide stakeholders with *access to a common view* of the experiments, but also the possibility to continuously *sharing the control* over the remote experiments. The system should also offer *synchronous communication tools*, as well as *social awareness tools*, to bring students the feeling of being connected with and supported by their peers and instructors (Lowe et al., 2009b). The remote lab environment should include *learning analytics tools* allowing tutors to monitor learners' activities so as to easily assist students facing with blocking situations with exactly the support they need (Bell et al., 2010). Instructors should also have the opportunity to *design experiments* through a user-friendly authoring tool to promote configuration and re-engineering of online experiments.

3.3.2.1 Massively scalable online architecture

The remote lab environment we designed (Bouabid et al., 2012b; Broisin et al., 2015), called Lab4CE (Laboratory for Computer Education), is illustrated in Figure 3.4 and based on a three-layered architecture inspired by the iLab proposal (Harward et al., 2004). Like prior works (Hardison et al., 2008), we adopted the iLab architecture because it combines federation of heterogeneous entities with modularity and integration features. The middleware layer integrates various services for seamless communication between the rich user interfaces and the laboratory layer hosting the resources upon which practical sessions are performed.

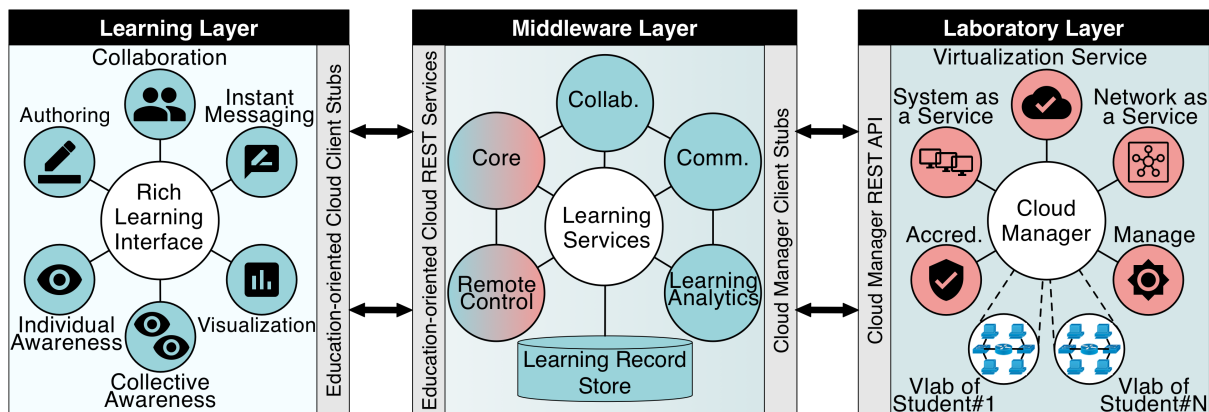


Figure 3.4. The three-layered architecture of the Lab4CE environment.

The laboratory layer stands on an Infrastructure-as-a-Service solution (i.e. OpenStack¹) to ensure the management of the virtual machines and networks offered to end-users, and of the accreditations assigned to them according to a role-based access control approach. We contributed to this layer by designing a standardised and generic model to enable fine-grained description of all entities hosted by the cloud manager (Bouabid et al., 2009a,b). The middleware layer acts

¹<https://www.openstack.org/>

as a broker. On one side, it exposes to learning interfaces a set of services whose orchestration is ensured by a set of distributed objects, whereas on the other side it concretely carries out actions on the virtual resources through the services provided by the laboratory layer. In this layer, our contributions relied on the learning analytics framework we designed to collect, store and process interaction data (Venant et al., 2016b), but also on collaboration and communication services (Broisin et al., 2017b). Finally, the learning layer exposes rich web interfaces for providing effective support to users during practical sessions. We designed various scaffolding tools and visualisations that extended existing VRLs and increased user inquiry-based learning experience (Bouabid et al., 2011; Broisin et al., 2017a).

3.3.2.2 Standard representation of laboratories and experiments

According to Seiler (2013), there was an urgent need for a standardised, unifying and generic approach able to cover any hardware and software resource or apparatus, whether it is real, virtual or hybrid, to encourage distribution of complex experiments across various institutions.

We suggested a standard representation built on the DMTF’s Common Information Model (CIM (DMTF, 2010)). We defined a laboratory as an administrative domain under the authority of a given institution and hosting physical and/or logical resources that can be used for (remote) practical activities, and suggested the matching modelling with almost no efforts (Bouabid et al., 2009a,b, 2012a). Indeed, CIM provides a set of native classes to define special grouping (e.g. a laboratory) serving as an aggregation point to associate one or more physical and logical entities (e.g. an apparatus, a simulation), and includes a general structure for representing networked topologies (e.g. interconnections between apparatus). After the study of the existing CIM models, we specified only three classes and five relations to build the domain-independent experiment model illustrated by the UML diagram on the left-hand side of Figure 3.5. Also, to meet the specificities of computer education experiments, we identified the CIM classes dedicated to the computer science area. The right-hand side of Figure 3.5 gives the rough modelling of a computer through existing CIM classes.

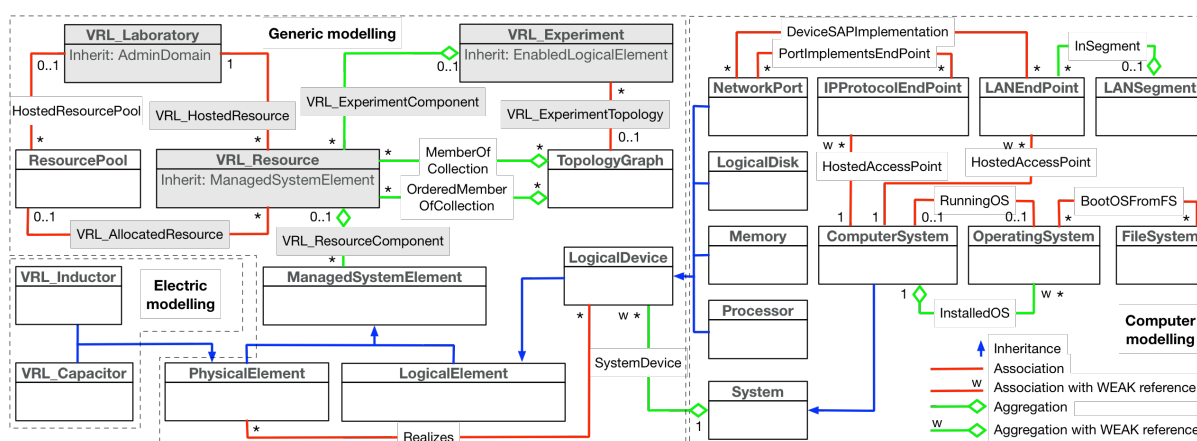


Figure 3.5. The standard modelling of an experiment.

Besides the operational model of an experiment, we designed a LOM profile on the basis of the metadata identified in (Richter et al., 2012), and introduced the concept of *experiment* as inter-

active learning object to consider both its pedagogical and technical aspects: *an experiment is an interactive learning object specifying the resources, together with their initial configuration and the possible interconnections between them, required to achieve a given (set of) learning outcome(s)*. According to this definition and to facilitate the design of computer education experiments, we implemented an authoring tool illustrated in Figure 3.6 and intended for learning designers. They can design their experiment at two granularity levels: they can draw the experiment topology by dragging, dropping and linking equipments, and then configure each component according to the underlying resource model. The tool generates a LOM record for sharing and reuse purposes, as well as a CIM-XML document describing both the topology of the experiment and the initial configuration of the resources. Within Lab4CE, this XML representation is mapped to the specific OpenStack format, and recorded into the laboratory layer. Let us note that this process does not trigger the deployment of any virtual resource. Instead, the personal virtual lab of each student is deployed on demand when learners access for the first time to the experiment.

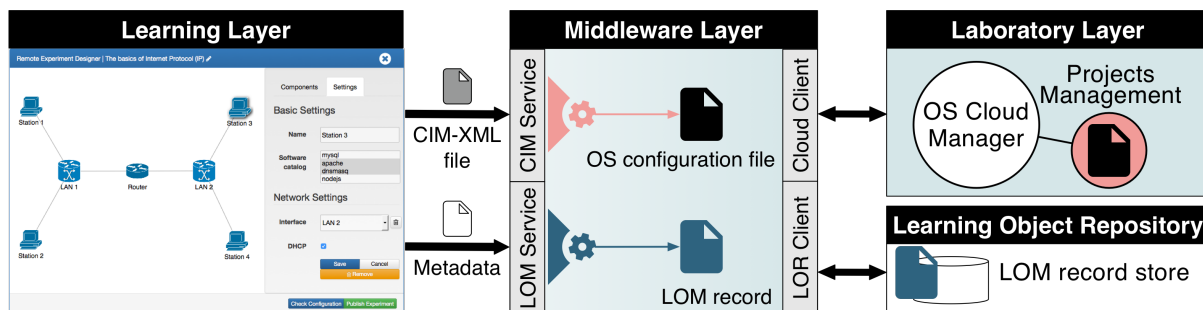


Figure 3.6. The experiment authoring tool.

3.3.2.3 Learning analytics infrastructure

In addition to ensuring communication between users and resources, the middleware layer integrates a learning analytics framework representing the cornerstone of the interactive tools presented further. We took as a basis recent works and standards from the learning analytics community and well established approaches such as the Migen project (Gutierrez-Santos et al., 2010) or the Go-Lab infrastructure (Hecking et al., 2014) to design a system able to collect, analyze, store and deliver information about the learning process. The resulting infrastructure is shown in Figure 3.7. The originality of our approach relies on the distribution of the components so as to benefit from distributed computing. Three loose-coupled components reside on the client side and exploit recent browsers capabilities to ensure the collect, aggregation and enrichment of data resulting from users' interactions with the GUI, whereas two stores located on the server side are respectively responsible for recording the rules to be solved, and for storing the (enriched) learning records. Basically, rules are published by human experts into the dedicated store, and the analytics engine acts as a subscriber of this store to receive rules and apply them to records delivered by the forger. Visualisations and tools presented further are subscribers of the Learning Record Store (LRS) to provide end-users with immediate feedback.

Our trace model adopts the xAPI specification for interoperability and sharing reasons. We created a custom generic xAPI activity object to represent any type of interaction between users and the remote lab environment. The matching data model can be found in (Venant, 2017).

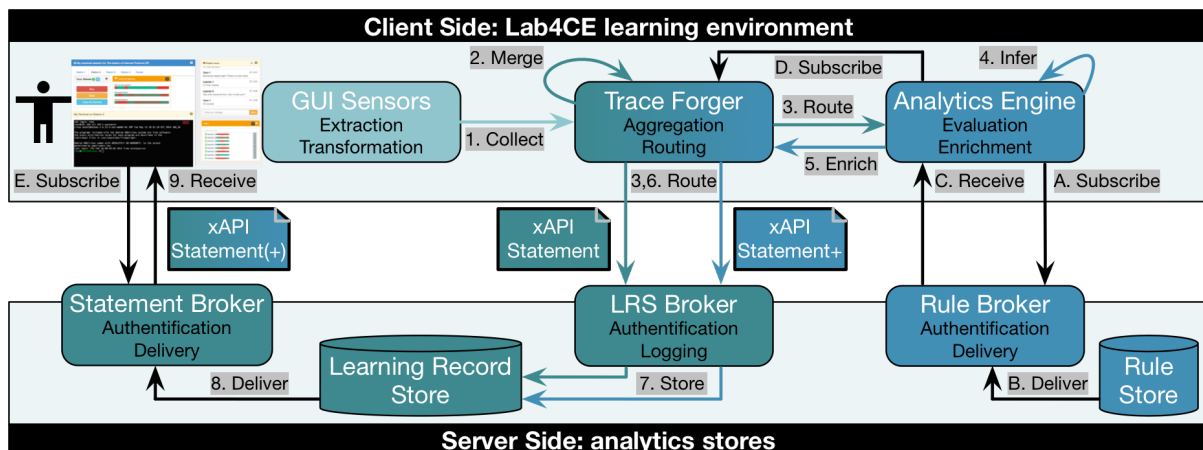


Figure 3.7. The learning analytics infrastructure.

Compared to the standard xAPI representation, one important extension we introduced is the attribute *indicators* which designates different valuable information that make sense from the learning perspective. We illustrated in (Venant et al., 2016a) how the technical rightness of an instruction, defined as *the ability of a learner to execute instructions on a target resource or apparatus without errors*, could be automatically evaluated in real time by analysing the response returned by the remote resource.

The technical performance addresses (self-)evaluation of performance when learners are faced with a concrete and practical situation. Computed on the basis of the technical rightness of a command, it brings an alternative to common performance evaluation techniques relying on acquisition of theoretical concepts and knowledge based on quizz or evaluation of learning paths (Lau and Yuen, 2011; Ritzhaupt et al., 2015).

3.3.2.4 Interactive features for enhanced inquiry-based learning

On the basis of the learner analytics infrastructure, we introduced new interactive features into the rich learning interface of Figure 3.8 to enhance user inquiry-based learning experience.

Social presence and comparison tools. Social presence tools are usually designed to increase the level of understanding when distant people have to interact with each other (Barrow, 2010). Such a component appears in top right-hand corner of the GUI to list the learners and tutors involved in the experiment the authenticated user is working on. It allows to quickly visualise the role of each stakeholder through a graphical icon (i.e. tutors are represented with a hood). According to the findings of the study by Swan and Shih (2005), "*instructor social presence has a significantly greater impact on perceived learning from online discussions when compared with the impact of student social presence*" (Pollard et al., 2014).

This tool is a key component as it represents the starting point for the interactive features. The menu associated to each user allows to initiate a collaboration with one or several learners and tutors, watch peers' Terminal, and exchange private messages. Also, our visualisation embeds a progress bar displaying the technical performance level of each student since they logged-on the system. Progress bars are components subscribing to the LRS for instruction statements,

The screenshot displays the Lab4CE interface with several key components:

- Technical rightness:** A progress bar showing the status of the current session, experiment, and all participants. Annotations indicate access to personal labs and resources of other users like Rémi Venant.
- Users:** A list of users including Julien Broisin, Romain Laborde, Rémi Venant, Patrick Magnaud, and Pierrick Marie. A menu offers actions like 'Talk in private', 'Ask for collaboration', and 'View the session'. Annotations point to 'Partners' Terminal thumbnails'.
- Terminal:** A central window showing the output of a `top` command on resource RT1. The output includes system statistics and a process list table.
- Chat Rooms:** Two chat windows are visible: 'Public room' and 'The personal room of Rémi Venant', showing messages and a 'Write your message' input field.

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
1	root	20	0	28592	4572	3056	S	0.0	0.9	0:03.72	systemd
2	root	20	0	0	0	0	S	0.0	0.0	0:00.00	kthreadd
3	root	20	0	0	0	0	S	0.0	0.0	0:00.06	ksoftirqd/0
5	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	kworker/0:0H
6	root	20	0	0	0	0	S	0.0	0.0	0:00.15	kworker/u2:0
7	root	20	0	0	0	0	S	0.0	0.0	0:00.95	rcu_sched
8	root	20	0	0	0	0	S	0.0	0.0	0:00.00	rcu_bh
9	root	rt	0	0	0	0	S	0.0	0.0	0:00.00	migration/0
10	root	rt	0	0	0	0	S	0.0	0.0	0:01.47	watchdog/0
11	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	khelper
12	root	20	0	0	0	0	S	0.0	0.0	0:00.00	kdevtmpfs
13	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	netns
14	root	20	0	0	0	0	S	0.0	0.0	0:00.12	khungtaskd
15	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	writeback
16	root	25	5	0	0	0	S	0.0	0.0	0:00.00	ksmd
17	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	crypto
18	root	0	-20	0	0	0	S	0.0	0.0	0:00.00	kintegrityd

Figure 3.8. The rich learning interface of Lab4CE.

and adopt a simple colour code (i.e. green if a command is technically right, red otherwise) to draw a colour shading in near real time as users type commands. These individual progress bars allow learners to identify peers that perform better, and to ask support from them using the tools presented further. Tutors can differentiate learners facing an occasional difficulty (i.e. students whose red items appear on the same part of the progress bar) from those facing a failing situation for a longer period of time (i.e. students whose red items are scattered all along the visualisation).

We reused the concept of progress bar to build a social comparison tool. This type of tool consists of social comparison feedback that allow group members to see how they are performing compared to their partners (Michinov and Primois, 2005), and brings students the feeling of being connected with and supported by their peers (Lowe et al., 2009b). Our comparison tool illustrated in the top left-hand corner of Figure 3.8 displays different levels of technical performance. The progress bars **My current session** and **My experiment** respectively provide the user with awareness about her technical performance since she logged-on the system, and since she started working on the given experiment (i.e. learners might need several sessions or days to complete an experiment). The progress bar **All participants** reflects the technical performance of the whole group of learners since they started working on the experiment. Through the current and experiment progress bars, learners get aware of the progression of their technical performance level. In association with the bar describing performance of all participants, they can self-position in relation to peers, whereas educators can adapt the overall difficulty and/or objectives of the practical activity.

Collaboration between peers. Learners can invite up to three fellow students into their personal virtual lab through the user block described above. In the context of a collaborative session, users must be aware of what others are doing on the apparatus, and of the feedbacks returned by the apparatus, so they can act accordingly. We adopted the artefact awareness approach, defined as "*one person's up-to-the-moment knowledge of the artefacts and tools that other distributed people are using as they perform their individual, ongoing work*" (Tee et al., 2009, p. 678). The aim of the visualisation we designed (Broisin et al., 2017b) is to provide users with awareness about (i) who is working on the same resources, (ii) what other people are doing on the shared resources, and (iii) what feedbacks are returned by the shared resources.

As both actions carried out by learners and feedbacks returned by virtual resources are recorded into the learning record store, the approach we adopted consists in broadcasting, using the message-oriented middleware pattern, partners' streams of records on the GUI of the other partners. When several users work together on the same virtual resource, the partners' Terminals appear as thumbnails in the GUI (see Figure 3.8) so that users get aware of who is working on what. Besides, when one of the users carries out an action on a shared resource, the title bar of her thumbnail becomes red to notify partners that one or several actions have been performed by someone else on the remote resource. Finally, users can zoom on a Terminal thumbnail by putting their mouse over it in order to see, as a live feed, what actions are being carried out by the partner, and what outputs are returned back by the remote virtual resource.

A variant of this streaming-driven visualisation is the reflection-in-action tool we designed. During hands-on practical sessions, learners are used to look at peers' workspaces in order to compare solutions and results or to find food for reflection. Our awareness tool aims to reproduce this behaviour in a remote setting and acts as a Terminal player where interactions occurring between users and remote resources can be watched as a live video stream. Unlike the collaboration tool featuring shared control of a resource, this visualisation offers read-only capability. Accessible from the individual progress bars, it is intended to leverage peer support: learners can easily identify peers performing well through the user block, and then look at their Terminal to study how they are achieving the learning tasks. Also, tutors can monitor what learners are doing or ask them to watch their own Terminal for demonstration purposes.

Instant messaging system. If the collaboration tool allows students to work collectively and to see what partners are doing, they can not talk to each other to share questions, ideas

and findings. Different techniques including audio/video-conference and 3D-chat (Röhrig and Jochheim, 2001) can be used to provide such capabilities, but the survey conducted by Lowe et al. (2009a) showed that 40% of students who regularly used a remote lab identified the instant messaging, or online chat, as the preferred method of communication.

The instant messaging service we designed is shown at the bottom of Figure 3.8. It distinguishes two types of rooms. One public room allows any user involved in the experiment to post messages. This room is suitable for general information and discussions, or help seeking. Also, one private chat room is owned by each learner to support communication during collaborative work. In such a room, only the owner, tutors, and collaborative peers have the required credentials to post messages. Private rooms are relevant to help partners coordinate their perceptions, actions and knowledge so as to achieve a certain degree of mutual understanding. Finally, we integrated a personal messaging service providing space for private interactions between users.

Reflection-on-action tool. We designed a reflection-on-action tool featuring detailed analysis of interactions between users and resources. The tool lets users easily drill down into deeper and fine-grained analysis of their own as well as peers' sessions of work. The visualisation is based on timelines to expose the data, where each node represents a command coloured according to its technical rightness so that learners can easily focus on the difficulties they experienced; details on this tool are given in (Venant et al., 2017b). Combined with the social presence tool, learners are able to seek immediate support from peers by analyzing the commands executed by users currently performing well. Tutors have the opportunity to highlight the commands learners have difficulties with, and adapt their strategies accordingly.

3.3.2.5 Experiments and results

Lab4CE has been evaluated into two distinct experiments, both conducted in an authentic learning context at the University Paul Sabatier Toulouse 3 within a course entitled "Introduction to computer systems" and included in the first semester of the Computer Science curriculum. For each experiment, students could access their own virtual Linux-based machine wherever and whenever they wanted to. At the time of the first study, Lab4CE integrated the collaborative and communication features only.

Experiment #1. The aim of this experiment was to investigate whether (i) the system had a positive impact on students' engagement in practical learning of the Linux operating system, and (ii) a correlation could be established between learners' engagement in the system and their learning achievement. 139 students participated in the experiment. In this study, *we did not force students to use Lab4CE, they could use the computers available within the classroom if they wanted to*. Statistics about the usage of Lab4CE showed that 71 students logged-on the system, and each of them opened almost 7 sessions that lasted about 40 minutes, for a mean count of commands per virtual machine higher than 770. That suggests a positive effect of the system on learners' engagement: more than 50% of the students used Lab4CE, whereas only 25% of them installed a virtual Linux-based machine on their own computer even if they were taught this task. Still, students mainly worked during week-ends. To measure the correlation between students' engagement in the system and their learning achievement, we considered their performance at the final academic test as the dependent variable. The analysis showed a significant positive Pearson correlation: $r = 0.41$, $p = .002$. Results showed that those students producing more code in the system achieved 70% of the right answers in the final test. They also revealed that

the activity level in the system could be a good predictor of students' achievement and useful to detect their difficulties. Regarding interactions between learners, only one collaborative session occurred during which students exchanged 7 posts. Besides, only 75 messages, i.e. about 1 post per student, were sent to the public chat room of the experiment.

Experiment #2. Once awareness tools have been integrated into Lab4CE, we conducted a second study with 80 students to investigate the impact of the awareness tools on students' perception of learning during a practical activity. We compared their perception while using two different systems: the Lab4CE environment and the classroom computers. The respective groups of students (i.e. the Lab4CE group, $N = 32$, and the control group, $N = 48$) filled the Constructivist Online Learning Environment Survey (COLLES) designed to measure different learning facets (Taylor and Maor, 2000), as well as the SUS questionnaire to evaluate usability of the tool. Details of this study are available in (Broisin et al., 2017a), only results related to the "interaction", "peer support" and "making sense" scales are given below.

Results from both groups are almost the same regarding the interaction scale which measures learners' educative dialogue and exchange of ideas. However, statistics showed that almost 30% of the Lab4CE students have collaborated at least once with a peer during each session of the experiment, and that students used the Lab4CE communication tool to exchange messages. Those results illustrated a significant increase of the level of interaction between students compared to the previous study. This might be explained by the enhanced social presence tool, as the technical performance analysis results showed that learners invited to collaborate performed well at the time of the request. Regarding the peer support scale, both systems were poorly evaluated, even if almost half of the Lab4CE students used the reflection-on-action tool to review peers' sessions. These learners fully benefited from peer instruction, as the mean technical performance level of learners whose the session has been analysed was 90 (for a highest score of 100). Finally, scores of the scale aiming at evaluating how messages exchanged between students make sense, revealed that students assessed Lab4CE with a higher concentration of distribution and a little higher class mean. These results showed that providing students with individual and collective awareness tools helps them to get a better comprehension of their interactions with each other. Last but not least, the SUS score raised to 73.6 for Lab4CE which, according to Bangor et al. (2009), makes it a *good* system in terms of usability.

3.3.2.6 Discussion and positioning of the works

A large number of projects and initiatives engaged and are still engaging significant efforts to study how traditional practical activities in different STEM disciplines could be offered to a wide range of students at different scales. The most representative research includes the iLab framework initiated in the 2000s by the Massachusetts Institute of Technology, the Library of Labs² co-funded by the Community Program eContentplus from 2009 to 2011, the joint Australian project LabShare³, the WebLab-Deusto⁴ developed at the University of Deusto, the Go-Lab⁵ (2012-2016) and Next-Lab⁶ (2017-2020) projects funded by the European Commission, the Lab2Go⁷ portal,

²<http://www.lila-project.org/>

³<http://www.labshare.edu.au/>

⁴<http://weblab.deusto.es/>

⁵<http://www.go-lab-project.eu/>

⁶<https://nextlab.golabz.eu/>

⁷<http://www.lab2go.net/>

or the Erasmus+ project VISIR+⁸ (2015-2017). We review here these initiatives by focusing on their contributions to the three-layered architecture widely adopted in remote labs.

Within the laboratory layer, prior research has mainly investigated the educational facet of experiments to promote their share and reuse through LOM or Dublin Core metadata and repositories (Grube et al., 2011; Mateos et al., 2012), but a lower attention has been given on how to describe labs, apparatus and experiences from the operational facet. The most significant initiatives stand on semantic web technologies (Gravier et al., 2012) to design generic but ad hoc models preventing interoperability. Instead, we capitalised on the CIM modelling to go beyond this limitation. We designed a unifying, technology- and domain-independent model characterised by a high level of abstraction and offering a formal and standard representation of simple and complex experiments. The generic and abstract classes we proposed can serve as a basis for subclassing entities specific to any real and virtual apparatus.

Regarding the middleware layer, interesting solutions to complex problems such as architectural design (Harward et al., 2008; Lowe et al., 2009b), reservation and queuing algorithms (Lowe, 2013), load balancing (Sancristobal et al., 2010), standardisation as smart devices (López et al., 2015; Halimi et al., 2017; Salzmann et al., 2018), or communication with the remote lab (de la Torre et al., 2020) have been suggested to feature shared control of apparatus. However, we noticed, like Heradio et al. (2016) in their review of research on VRL in education, that very few researchers (van Joolingen et al., 2005; Gillet et al., 2005; Gustavsson et al., 2009; Jara et al., 2012) tackle collaborative learning. Remote audio/video surveillance (Lowe et al., 2013; Melkonyan et al., 2014; Khattar et al., 2016) or virtual network computing (Xu et al., 2012; Leproux et al., 2013; Gampe et al., 2014) represent common practices to get feedback from the remote apparatus. These approaches provide a live view of the status of the remote laboratory, but it is very difficult for users to correlate this status with the actions performed by peers. Other solutions rely on virtual reality toolkits (Peña-Ríos et al., 2012) to provide feedbacks to users, but they prevent a detailed and effective tracking of users (Lowe et al., 2009a) and increase the cognitive load. The middleware layer we designed embeds a fully domain-independent learning analytics framework based on both a distributed modular architecture, and a generic data model. Adoption of the xAPI standard also brings large scale interoperability and sharing capabilities to our LRS. Our innovative streaming-based approach relying on this framework to support collective and collaborative sessions offers awareness of activities performed simultaneously by several users on the remote apparatus. It thus opens new opportunities to develop team work in VRL, one the 21st century skills that must be addressed by the next generations of remote labs.

Nonetheless, other works from the VRL community also built on learning analytics to enhance the learning layer with support of reflection (Mikroyannidis et al., 2015), post-activity students evaluation (Romero et al., 2014; Wuttke et al., 2015), laboratory usage assessment (Orduña et al., 2014a), or analysis and understanding of the learning process (García-Zubia et al., 2019). These systems record learners' activities at different time scales, and expose rich dashboards offering different visualisations instrumenting the above features. Such systems can be used for retrospective analysis of learners' behaviours, but the dashboards' complexity, combined with the request/response paradigm they are based on, are not suitable for live analysis requirements where feedback has to be easy to understand as well as automatically refreshed in real time. Our visualisations built on the publish-subscribe messaging pattern to implement an

⁸<https://visir.ifsc.edu.br/>

architecture based on web sockets able to return real-time feedback to learners, and are fully integrated into the working space as lightweight components to avoid additional cognitive load and split attention effects. However, first experimental results showed that our approach did not significantly promote peer support. To increase the feeling of learners on how peers encourage their participation or value their contributions, dashboards providing students with awareness about reviews performed by peers on their own work could be proposed.

Finally, while efforts from the educational sciences are being conducted to investigate how to enact modelling and simulation practices in engineering education (Magana and de Jong, 2018; Hovardas et al., 2018), some approaches integrate a set of scaffoldings around the lab to formulate hypothesis and share the findings of experiments between students (d'Ham et al., 2019). Also, tools for educators have been developed to ease authoring of learning scenarios: the Go-Lab portal⁹ allows teachers to define learning scenarios through the concept of inquiry learning spaces composed of learning resources, scaffolding apps and online labs (Govaerts et al., 2013), while other initiatives (Orduña et al., 2014b; Tawfik et al., 2014) stand on SCORM to make pedagogical resources and practical activities available to students. Also, recent research offers the opportunity to students to design their own experiment through design tools (van Riesen et al., 2018; Efstathiou et al., 2018). These efforts provide educators with the opportunity of designing learning scenarios at a macro level, but remote labs can not be configured according to specific objectives, and experiments of a given lab always suggest the same tasks to learners. We developed an easy-to-use micro authoring tool to ease the design of experiments characterised by a strong flexibility in terms of topologies and settings of apparatus. As a consequence, this tool is tightly coupled with the learning domain and requires significant modifications to comply with the experiment model of another discipline or apparatus. To address the complex challenge of automatic generation of authoring user interfaces, solutions based on ontologies and/or model-driven approach could be investigated starting from the modelling of experiments we suggested.

3.4 Conclusions

Our contributions to promote active learning in large group instruction relied on the proposal of two different systems. First, based on existing approaches devoted to formative assessment, we developed Tsaap-Notes. This system integrates an innovative Think-Pair-Share process comprising new learning tasks and activities to strengthen strategies that are of most importance in the context of large group instruction. By combining interactive capabilities with knowledge building approaches supported by peer instruction and peer assessment, Tsaap-Notes addresses activities and strategies fostering effective formative assessment while engaging a large amount of students in this type of activity. Second, our research on remote practical learning led us to design an education-oriented cloud provider for computer education. Lab4CE was built on a modular architecture standing on a mix of standard specifications and learning analytics technologies, and integrates simple and easy-to-use visualisation tools. The novelty of our approach resides in the relevant and efficient use of these standards in a remote lab environment to expose interactivity-rich user interfaces engaging learners. Both systems can easily be integrated in virtual learning environments as tool providers, as they have been designed to support the Learning Tool Interoperability protocol. Our contributions thus provided higher education institutions with interactive

⁹<http://www.golabz.eu/>

and engaging solutions to face the growing number of students, whether learning takes place in face-to-face, distant or blended settings.

Several limitations have still to be tackled to strengthen our proposals. One general limitation is related to their evaluation. First experimental results showed that our proposals increased learners' level of engagement in their activities, as well as their level of understanding. However, more studies are needed to strengthen these outcomes and evaluate our tools in terms of effective learning gains. Also, these studies have to involve a wider range of instructors to get feedback about the usability of both systems, as until now they have been mainly used by their designers and developers. Regarding the TPS-oriented process integrated into Tsaap-Notes, it lacks collaborative strategies such as actual discussions between learners to promote sharing of ideas and knowledge building. Indeed, the socio-cognitive conflict of our process makes students think individually based on peers' answers and rationales before submitting their definitive answer, but they can not exchange and argue about the divergent points of view. The use of microblogging tools during lectures in large classes has demonstrated a number of benefits, including learners' engagement in providing peer feedback (Luo, 2016). This approach could be integrated into our process to allow group discussion and increase collective reflection. Finally, the reflection-on-action and social awareness tools integrated into Lab4CE have been developed on the basis of learners' technical performance, i.e. their ability to manipulate the remote apparatus without errors. Even if this approach applies to a wide range of STEM disciplines and laboratories, it does not inform about the resolution of the given problem by learners. To increase accuracy of these tools, additional information revealing strategies adopted by learners as well as their progress in the experiment is required. We initiated some preliminary works to identify behavioural strategies leading to good academic performance in computer education (Venant et al., 2017a), but deeper investigations are needed to provide users with more effective feedback automatically.

In terms of implications of these works, Tsaap-Notes has recently been updated, both at the graphical and technical levels, and renamed as Elaastic. Based on this system, the B4FORMATIVE! project has been established between our team and the academy of Nancy-Metz. This academy is pioneering the bringing your own device approach at school through its involvement in the Num@venir project¹⁰ whose general objective is to increase students retention. The B4FORMATIVE! project is funded by Direction du Numérique pour l'Éducation from 2019 to 2022, and aims at designing, deploying and evaluating a system promoting quality formative assessments, from both the students' and instructors' perspectives. More specifically, the objectives of the project are to investigate how formative assessments can help learners to self-evaluate their knowledge, better position themselves in relation to peers, and promote self-regulated strategies. More details on this project are given in my research programme.

3.5 Related publications

Bey, A., Pérez-Sanagustín, M., and Broisin, J. (2019). Unsupervised Automatic Detection of Learners' Programming Behavior. In *Proceedings of The 14th European Conference on Technology Enhanced Learning (EC-TEL)*, pages 69–82, Delft. Springer.

¹⁰<https://numavenir.com/>

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- Silvestre, F., Vidal, P., and Broisin, J. (2015a). Online tests based on contributions provided by teachers and students during face-to-face lectures. In *Proceedings of The 15th International Conference on Advanced Learning Technologies (ICALT)*, pages 29–33, Hualien. IEEE.
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- Silvestre, F., Vidal, P., and Broisin, J. (2015b). Qualification semi-automatique de contributions d'apprenants pour l'intégration de feedbacks de qualité dans les tests en ligne. In *Proceedings of The 7ème Conférence francophone sur les Environnement Informatique pour l'Apprentissage Humain (EIAH)*, pages 210–221, Agadir. ATIEF.
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Conclusions and future directions

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This chapter closes the manuscript. It first reviews the main contributions addressing the research questions emphasised in the introduction of this document, before focusing on my research programme for the coming years.

Review of contributions

All contributions of this work have been organised around three main challenges: (1) Development of open educational resources and competence-based curriculum; (2) Quality-oriented monitoring of user learning experience; and (3) Design of interactive learning systems to foster active learning.

The first chapter addressed the first challenge and presented our main contributions about high-quality open educational resources and competence-based curriculum to promote global learning. Specifically, we studied the context of highly decentralised TEL environments where geographically distributed partners have to develop OERs. This complex setting introduced a number of research questions related to OER management, metadata and tools to support the various stakeholders. To tackle these questions, our first contribution was the development of an OER lifecycle facilitating collaborative design through the explicit description of what has to be done, when and by who. The second contribution was related to the identification of the metadata required to instrument this lifecycle, and the specification of a role-based and progressive process to semi-automatically generate these metadata. With regards to competence-based curriculum, our third contribution relied on a model unifying academic and professional approaches around the concepts of skills, knowledges and attitudes. The fourth contribution consisted in the development of a web platform¹¹ exploiting the competence model and offering different services and tools to learners, teachers, coordinator of curriculum, and professionals. The main tools offered teachers the opportunity to design curriculum, and provided learners with recommendations of curriculum

¹¹<http://miage-competences.francecentral.cloudapp.azure.com/#/>

and awareness about their competence development all along their training. All contributions in this chapter were developed in the context of two international projects respectively investigating the design and dissemination of open textbooks in Latin America and sharing of educational resources in Europe. The results of this research also contributed to the LOM-FR application profile definition together with the AFNOR association. The future directions on this line of research are described in the research programme.

The second chapter has addressed the challenge of how to increase user learning experience in TEL environments through personalised learning. Our contributions focused on monitoring of users' activities in learning systems and beyond, in order to build the knowledge required for the personalisation process. The research has been developed to satisfy two strong requirements: to propose solutions as generic as possible, but also semantically rich and usable; to ensure quality of the collected data. To address the research questions about federation of highly heterogeneous traces, support of meaningful indicators and users privacy, we adopted a standardised data-driven approach built on system and network management initiatives. As a first contribution, we proposed a model of high resolution and abstraction level, and demonstrated how it can be extended to fit specific personalisation needs. The second contribution was a privacy-aware architecture standing on a principle from the security area that consists in splitting and storing the tracking data into different locations, so as to prevent access to the whole set of data. Research questions related to the quality of the data collected by the monitoring system have been tackled through the requirement engineering approach. We proposed as a third contribution a goal-oriented methodology guiding the design of platform-independent adaptation logic. The fourth contribution was a set of patterns for quality-oriented self-monitoring that drive the monitoring process and the associated components. Our contributions have been validated through federation of heterogeneous data sets and development of adaptive systems on one hand, and application of the methodology to a case study related to management of a datacenter for computer education on the other hand. Some of these works also served as a basis for building a social data infrastructure in the Open Discovery Space project¹². Future directions are to exploit the collected data in adaptive systems for making personalisation more intelligent. More details about these future directions are given in my research programme.

Chapter 3 addressed the challenge of defining sustainable and innovative learning processes and tools to foster active learning. The objectives of these works were to provide higher education institutions with learning systems able to support a growing body of learners, while maintaining tuition costs and ensuring quality of curricula. The first contribution was a process to support the think-pair-share strategy in large groups that can be instrumented in face-to-face or distant settings, and the tool Tsaap-Notes implementing this process as a formative assessment system. The second contribution was Lab4CE, a learning analytics solution to promote learners' social interactions and collective activities in remote laboratories. This web-based inquiry environment for computer education offers large groups of students the opportunity to develop their skills and professional competences whenever they need it. Tsaap-Notes and Lab4CE are more than proof-of-concepts, they are mature tools that have been developed under the GNU Affero General Public License. Tsaap-Notes has been released as open source software¹³ thanks to a fruitful

¹²<https://portal.opendiscoveryspace.eu/en>

¹³<https://github.com/TSaaP/tsaap-notes>

collaboration with the Ticetime company¹⁴. Lab4CE will also be made available to the TEL community once code cleaning operation is completed.

First experiments in different authentic learning settings showed that both systems increased learners' engagement in activities. Also, a recent experiment has been conducted with researchers of the Praxiling laboratory¹⁵ to assess the collaborative features offered by Lab4CE. First analysis show that the instant communication tool, combined with the artefact awareness tool, can be used to support peer tutoring. We will have in the near future good opportunities to expand our knowledge on the impact of these tools. On one hand, Elaastic¹⁶, the new version of Tsaap-Notes, will be disseminated in the European Erasmus+ project Prof-XXI¹⁷ community, and experimented at a large scale in high schools of the B4MATIVE! project I coordinate. On the other hand, the recent collaboration with researchers of the LIUM laboratory¹⁸ will offer the opportunity to experiment Lab4CE in other learning contexts. Research avenues to enhance both formative assessment activities and computer education are given in the following section.

Research programme

The number of students in higher education significantly increased over the last decade. According to the last prediction of the French ministry of Higher Education, Research and Innovation dated from April 2020 (Pauron, 2020), this number will continue growing in the next ten years. French HEIs will have to face with an increase of 133,000 students in 2028 (i.e. a raise of 5%), compared to the number of students registered at universities in 2018. In addition, the current social and economical contexts caused by the COVID-19 have shown that higher educational institutions have to adapt to unexpected circumstances and implement hybrid and full distant learning, even if they are not yet ready to propose effective and solid solutions in response to these learning settings (Le Monde, 2020). These new circumstances make distant and blended learning the strategies of the future to train students in HEIs, but also to strengthen life-long learning. Technology-based learning tools driven by structured pedagogical approaches are the large scale solution to ensure pedagogical continuity in these changing learning contexts. Technological systems, together with systematic data collection processes and artificial intelligence methods, will become the center of the future educational contexts. In their report on Artificial Intelligence (AI), Villani et al. (2018) highlighted that AI brings new opportunities to train a large number of students in an adaptive and personalised manner. Providing HEIs with the technological scaffold they need to better support the learning and teaching tasks represents the main direction of my research programme. I will specifically investigate the two following lines of research: (1) intelligent systems to support stakeholders in massive learning settings, and (2) meaningful competence-based personalised learning.

¹⁴<https://ticetime.com>

¹⁵<https://praxiling.cnrs.fr>

¹⁶<https://elaastic.irit.fr>

¹⁷<http://www.profxxi.org>

¹⁸<https://lium.univ-lemans.fr/en/lium/ieiah/>

Intelligent support in massive learning settings

This research line addresses the design of intelligent support in massive learning settings and builds upon the works presented in Chapter 3. The main aim behind this research project is to put data mining and learning analytics to the service of education to better support both teachers and learners in massive learning settings. This research project is structured around two research axes that will explore learning at scale in (1) computer science disciplines, and (2) formative assessment activities. Both axes will require the analysis of learners' behaviour to intervene when necessary and maximise learning.

Supporting computer education at scale

The growing demand for programmers over the last decade (Le Monde, 2016) has led to a significant increase of initiatives to integrate computer education in curricula. These efforts have resulted in, for example, policies to integrate computer education as part of high school curriculum (e.g. the new option *Numérique et Sciences Informatiques* in France), or national training courses to update programming skills of professionals (e.g. in Finland, with a completely free online course to understand artificial intelligence). But widening the training sector also means supporting practitioners regarding the variety of problems and situations they have to deal with when teaching and learning computer science.

Thanks to the large amounts of data collected through computer education environments, research on learning programming have moved in the recent years from subjectively anecdotaly-oriented, to empirically-based and data-driven methods (Ihantola et al., 2015). Some researchers have focused on learners' data to automatically analyse students' coding behaviour and propose a qualitative classification of their programming profiles (Blikstein, 2011). Recent prior works go further, and use data mining techniques for proposing models that predict successful coding strategies (Sharma et al., 2018), programming problem-solving time (Kato et al., 2017), or students' performance (Wang et al., 2017; Estey et al., 2017). However, to transfer these academic results to solutions supporting teachers and students in actual contexts, researchers face one major challenge: the lack of methods to automatically analyse data from different learning contexts and scenarios, to provide support on real time. Solutions to characterise and classify students' programming behaviour proposed so far in the literature are limited when applied to data from other learning scenarios, or to large groups of students, or to extended periods of time. To expand our knowledge on how to support computer education, it is key to provide the research and practitioner communities with (1) new unsupervised analytical methods, applicable to any programming context, and capable of being transferred to actual solutions, and (2) innovative scaffolding systems to bring intelligent support to students.

Unsupervised analysis of learners' behaviour. Current research addressing analysis of students' data provide insights on features and methods to detect behavioural patterns for student classification (Perkins et al., 1986; Blikstein, 2011) or building learners' models that correlate with students' performance (Wang et al., 2017; Sharma et al., 2018). However, prior works are limited when looking for mechanisms to automatically detect and classify learners' behaviours. Firstly, scientific publications on methods for features extraction use datasets from a single learning context, which makes them hard-bounded to it and not directly applicable to datasets extracted from other scenarios. Only a recent study (Price et al., 2018) goes beyond and proposes an analysis

with two different datasets for evaluating the quality of data-driven hints in intelligent tutoring systems for learning programming. More studies of this type, applying the same analytical methods to different datasets, are required for advancing research in computer education. And secondly, most of studies proposing methods for categorising learners' programming behaviour require human intervention at some steps. In some cases, they use supervised machine learning algorithms that require a person to discriminate good or bad learners' classification (Kato et al., 2017; Wang et al., 2017). In other cases, they assume qualitative learners' categorisation in prior steps, or stand on students' performance provided by teachers in advance (Sharma et al., 2018). Thus, new generic and unsupervised approaches, transferable to different contexts, are required to categorise and classify learners' behaviour in order to provide teachers and students with actionable information to support them in their tasks. I will build upon this prior work to address the following research question: What features better represent students' learning programming behaviours, and what unsupervised data mining methods are the most appropriate to automatically identify and classify them?

I have until now initiated preliminary studies about analysis of learners' behaviour in two disciplines of computer science: system administration, and programming. In the context of system administration, we studied students' learning strategies using pattern mining for analysing high-level programming actions from data collected in authentic settings (Venant et al., 2017a). Results highlighted correlations between some of the strategies and the students' academic performance. This study was performed using a dataset of 107 first-year students from the Computer Science Institute of Technology of Toulouse. A short-term plan is to use two additional data sets that have been collected in the same learning context to replicate the analysis. Even if some relations between learners' behaviour and performance are confirmed, further research is needed to study what the causal links between these two variables are, and to propose predicting models for identifying those factors that could maximise students' success. Also, to assess the generability of the methods, I plan to apply these same pattern analysis to other STEM disciplines. For instance, in the LaboREM system dedicated to electronics education (Luthon and Larroque, 2015), students give a value to several parameters of different devices before launching a simulation to analyse a physical phenomenon. In this study, like in the system administration case, learners carry out actions using various parameters in their labworks. My hypothesis is that we could use similar analytical methods of those used in the case of computer education to analyse learners' behaviour in other learning contexts by reusing and adapting both the nature of actions analysed and the identified learning strategies.

For the specific topic of learning programming, I seek to propose generic methodologies to automatically classify novice programmers. In a recent work, we proposed a three-phase process that applies unsupervised clustering techniques for automatically identifying learners' programming behaviour (Bey et al., 2019). We analysed data collected during a shell programming course, and identified (i) a list of features that improve the quality of the automatic learners' profiles identification process, and (ii) some students' behavioural trajectories correlated with their performance at the final exam. In addition, using the same data, I initiated preliminary research to define an indicator reflecting the semantic proximity of two source codes to express learners' capacity of solving a given problem (Broisin and Hérouard, 2019). This indicator, based on an edit distance algorithm, can be used to automatically classify source codes semantically as correct or incorrect in 58% of the cases. Moreover, the results of this work show that this semantic classification is correlated with teachers' evaluations of students' codes. To evaluate method-

ological solutions intended to support computer education in different learning contexts, further investigations addressing different programming languages are required. To this aim, I initiated a collaboration with researchers from the Norwegian University of Science and Technology. Based on the datasets provided by these collaborators and collected in Java and Python programming courses, the objective is to design a set of methodologies and unsupervised analysis methods able to classify learners according to their activity. My aim is to propose solutions requiring a minimal set of students' behavioural data and as context-agnostic as possible, in order to facilitate the application of these methods at scale.

In all the above studies, as in recent works assessing students' behaviour (Filvå et al., 2019; Pereira et al., 2020), the learning strategies describing learners' behaviours have been defined intuitively, on the basis of the features identified from the analysis. However, to facilitate cross-validation and replication studies, there is a need for a formal representation of these strategies. I plan to investigate, in collaboration with experts in educational sciences, how to propose a consistent taxonomy to describe these programming strategies aligned with existing educational theories. Proposing a theory-based taxonomy of strategies for computer education could be a starting point for studying learners' behaviour in different learning situations. To this aim, I have recently established a collaboration with a researcher from the Faculty of Psychology and Educational Sciences at the University of Munich. With this researcher we started studying how the cognitive process involved in writing programming code can be related to those actions that we conduct when writing texts (Flower and Hayes, 1981). Indeed, solid theoretical foundations in psychology that classify and identify the strategies applied by writers when creating an essay (Roussey et al., 1990; Piolat and Roussey, 1991) could be applied to learning programming.

Enhanced self-regulated learning. Self-regulated learning (SRL) is defined as the ability to engage with (meta)cognitive, affective and motivational processes in order to achieve learning goals (Zimmerman, 2000). Prior works provide empirical evidences on the relationship between students' self-regulatory skills and strategies, and programming performance. Some researchers showed that students' self-regulation traits such as motivation and self-efficacy correlate positively with good performance in programming tasks (Castellanos et al., 2017). Other researchers demonstrated that students who perform well in programming use more metacognitive and resource management strategies than lower performers (Bergin et al., 2005), and that self-regulatory variables can be used to discriminate between high and low academic performers (Echeverry et al., 2018). Based on these evidences, some researchers have developed educational tools for supporting computer science students in developing those SRL strategies that could help them learn programming concepts and develop programmes. Most of existing approaches in this line are summarised in the systematic literature review by Garcia et al. (2018), which shows that tools designed to support strategies such as self-evaluation, monitoring, organisation, goal setting, and strategic planning are good on supporting students in their programming tasks.

However, these authors also highlight that aspects such as environmental structuring and seeking social assistance are not well covered in current literature, and that automated assessment for supporting students' metacognition and self-reflection should be further studied. In addition, they indicate that current research does not present students' growth in self-regulated skills, opening up an opportunity to propose new platforms for engaging learners in SRL strategies while programming. Based on this prior work, I propose to design, implement and evaluate technological solutions for supporting learners' development of those SRL skills needed for programming learning. Specifically, I will extend the Lab4CE environment with new intelligent functionalities,

and evaluate them in actual learning contexts to analyse their effect on learners' programming behaviour. I will address the following research questions: What are the best mechanisms to support self-regulated strategies in programming learning environments? What is the impact of these mechanisms on students' programming behaviour?

To explore this field of research, I will follow the Interactive Learning Design framework (Bannan-Ritland, 2003) which organises the research process into four phases: (1) informed exploration; (2) enactment or implementation; (3) evaluation of local impact; and (4) evaluation of broader impact. In this framework, which will be applied as a continuous cycle, I will identify actionable information from the learners' behaviour analysis, and design new intelligent functionalities to drive learners towards the most successful behaviours. In a short-term perspective, and based on the identified behavioural patterns and semantic indicator, I will integrate into Lab4CE additional features to evaluate their impact on learners' SRL strategies. To exploit learners' strategies, I will design an intelligent system able to guide students towards the most appropriate learning trajectories so as to facilitate self-regulated learning. For introducing the semantic indicator, I will enrich the awareness tools presented in Chapter 3 with a visualisation dedicated to this indicator. Thus students will be provided with both a technical indicator informing about their capacity to syntactically master the programming language, and a semantic information revealing their capacity to solve real problems.

Expected contributions. One expected contribution of these works is to provide the research and practitioner communities with guidelines and methods for analysing learners' programming behaviour and detecting effective and ineffective learning trajectories. This research will also contribute to strengthen and generalise the findings of our prior works, but more importantly, to provide a mechanism for monitoring learners' behaviours across different disciplines and learning settings in a homogeneous manner. At a higher level, automatic detection of learners' behaviour will open up new opportunities to develop the next generation of tools intended to support computer education.

The intelligent systems developed in this line of research will serve as proof of concept to expand existing knowledge on tools designed for supporting learning programming, and to promote the use of automatic systems analysing behavioural changes for supporting SRL strategies. Dashboards and visualisations will also contribute to early detection of at-risk students and support informed decision-making. Finally, the collaboration with European partners will facilitate the convergence and transposability of the proposed approaches and solutions, and serve as a basis for expanding European initiatives on computer education.

Educational data mining and analytics for formative assessment

The main purpose of formative assessment is to provide feedback to students about their knowledge, so they can study in depth the notions and concepts they do not master. Prior research on formative assessment tools poorly exploits the data produced by students. In most of the existing systems, the feedback provided to learners is limited to statistics about the number of correct and incorrect answers in the form of histograms, pie charts or other visualisations to represent numerical data. Yet, current formative assessment tools gather more and more data during a formative assessment session that can be exploited to enrich the feedback delivered to students, but also to teachers. This is the case of the Elaastic tool which collects the answers to the questions, but also the rationales written by learners to justify their answers. In addition to these

data, Elaastic also collects the level of confidence that the students have to the answer, as well as ratings assigned to peers' rationales. To benefit from these collected data, the challenge is to understand how they can be used and analysed for improving learners' and teachers' support in formative assessment activities. In this regard, my objectives are twofold: (1) to investigate how to promote learners' self-reflection using natural language processing, and (2) to provide teachers with visualisations featuring both actionable information for helping them intervene to support students, and information about the quality of the posed questions to better design their formative activities. This line of research will be mainly developed in the scope of the B4MATIVE! project¹⁹ which involves a unique authentic learning setting comprising more than forty high schools to experiment our future proposals.

Natural language processing-enhanced learning. One objective of the think-pair-share process is to convince students who submitted a wrong answer at the first phase, to understand and trust the alternative rationale matching with a good answer so they change their response at the second phase and further study the concepts involved in the alternative. For improving the current answer assignment algorithm (see Section 3.3.1.2 for the explanation of the algorithm), I plan to study how to increase the rate of wrong-to-right students. Recent works proposed solutions to automatically detect inappropriate rationales (Gagnon et al., 2019). However, these systems do not propose a solution to detect those rationales that promote learning. My plan is to look for solutions on this line using the most recent research in the area of Argument Mining. Argument mining emerged in the past ten years and gained strong interest in the community since 2014 (Lippi and Torroni, 2016). This recent research area aims at identifying and extracting argument components and structure from both text and spoken language, so as to provide computational models based on machine learning with structured and annotated data (Lawrence and Reed, 2020). According to recent reviews about argument mining (Lippi and Torroni, 2016; Cabrio and Villata, 2018), argument mining has been mainly explored in education with two types of texts: student essays and scientific articles. Argument mining of student essays intends to identify argument components and structures (Stab and Gurevych, 2017; Eger et al., 2017), or to design automatic scoring systems (Nguyen and Litman, 2018). The primary objective of mining scientific articles was to identify rhetorical authors' moves (Teufel and Kan, 2009), but more ambitious goals such as assessing quality of the related work section (Casey et al., 2019) or supporting tutors' essay assessment practices (Bektik, 2017) are now in the focus of the community. In the context of formative assessment, learners' writing style and length of the rationales largely differ from argumentations that can be found in essays or scientific articles. Our challenge is, thus, to build upon prior research in argument mining to propose machine learning models for identifying the best rationales in an automatic and intelligent way. To address this challenge, I will especially study the following research questions: What machine learning models are best suited for automatically detecting quality learners' rationales in the context of formative assessment activities? What are the effects of persuasive rationales on learner's self-reflection?

Machine learning models dedicated to the various phases (i.e. argument identification, argument component classification, and argument discourse analysis) of the traditional argument mining pipeline (Wambsgans et al., 2020) have been identified (Lippi and Torroni, 2016; Cabrio and Villata, 2018). These models could potentially be adapted to identify the argument components of students' rationales when justifying an answer in the context of formative assessment. However, since my objective is to identify the most convincing, persuasive argumentations, I

¹⁹<https://www.irit.fr/b4mative/>

need to find a way for assessing the quality of an argument. Two different approaches could be investigated for argument assessment: (1) to automatically compute a rationale score to build a ranked list of arguments, or (2) to compare a pair of arguments to find out which of the two is the most convincing. These approaches have been experimented in recent articles with promising results (Habernal and Gurevych, 2016b; Simpson and Gurevych, 2018; Gleize et al., 2019). On the one hand, the ranking approach shows highly statistically significant correlations between predicted and human-annotated rationale scores, as the Pearson's r might rise up to .47. On the other hand, the pairwise comparison approach with models such as support vector machine, bi-directional long-short term memory and Siamese network obtain an accuracy of about 0.80 for predicting the most convincing argument in a pair.

Even if this prior work represents a solid basis that could be potentially adapted to the formative assessment context, several challenges still need to be addressed. First, there is a need to evaluate whether the models apply to all educational topics, or if some of them are more appropriate to a given topic than to another. For instance, rationales of students in the field of mathematics or physics might include various formulas and equations, whereas rationales in computer science might require analysing learners' source code. Mathematical and programming languages require specific adaptations compared to full natural language writings. Second, most of data sets dedicated to argument mining assessment are extracted from English writing users. This is the case, for example, of the IBM-EviConv²⁰ and UPKConvArg (Habernal and Gurevych, 2016a) data sets used in the prior works. However, to the best of my knowledge, there are no French open educational data sets to be used for training and evaluating the argument mining algorithms. Finally, learners' writing and argumentation capabilities evolve over time. Students at universities are supposed to have more advanced argumentation skills than K-12 learners, and models performing well in one context (e.g. higher education) might lost accuracy in another context (e.g. high school).

To face these challenges, I propose a research plan with two main objectives. The first objective is to generate a French-spoken argument data set comprising written data from different disciplines. A data set with data collected by Tsaap-Notes and Elaastic from 2014 is already available. It includes more than 20,000 items associated to around 900 questions and 5 different topics. Each record comprises, among other data, the correctness of the answer, the associated rationale, and the peer assessment average score of the rationale. This data set has been extracted from experiments mainly conducted in higher education, but additional data from experiments involving high schools of the B4MATIVE! project should be gathered by the end of 2020, 2021 and 2022. Also, collaborations with researchers from other french-speaking countries will contribute at enlarging the data set with information from different disciplines and learning contexts. One example of a tool that could help enlarge the data set is myDALITE (see Section 3.3.1.5) already deployed in several universities of Montreal. The data collected with myDALITE could help reinforce the algorithms to be designed. Once the data set will be generated, I will assess the effectiveness and precision of the existing argument mining models in order to design the algorithm that best fits the data set. Finally, the resulting model will be integrated into Elaastic, and several experiments will be conducted. These experiments will be designed so as to compare an experimental with a control group of students to assess the learning impact of the pairing algorithm on learners' performance and reflection.

²⁰https://www.research.ibm.com/haifa/dept/vst/debating_data.shtml

The second objective is to investigate how argument mining can be applied to enrich students' feedback in formative assessment tools so as to maximise learning gains. The various indicators resulting from students' rationales mining, including information such as the processed score of arguments, or relevancy of their structure, will be presented to learners and teachers through dashboards with different visualisations. The dashboards will be interactive so as to provide students with awareness about their knowledge, to help them self-compare with their peers, and to enhance their self-regulated learning skills. Recommendations and good practices on dashboard design will be taken into consideration so as to avoid data misinterpretation or one-size-does-not-fit-all problem, and to expose timely, general and detailed feedback (Verbert et al., 2020).

Quality formative assessment questions. Development of quality formative assessment activities pursuing students learning gains relies on (i) writing relevant questions; (ii) proposing distractors (i.e. typical learner responses to these questions); and (iii) providing good feedback to learners. Formative assessment questions can be considered as learning objects, as defined by IEEE. Lots of studies have been conducted for manually or automatically assessing the quality of a learning object. However, most of prior work propose models related to assessment from a quantitative (Ochoa and Duval, 2009), structural (Sanz-Rodriguez et al., 2011) or maintainability (Zimmermann et al., 2007) perspective, disregarding the educational aspects. My objective of this research project is to propose mechanisms and methods to assess the quality of a question from an educational perspective. The final aim is using these methods to propose systems that promote evidence-informed decision-making and facilitate sharing and re-use of questions so as to help teachers enhance their formative assessment practices. With this aim, my research project in this line will address the following research questions: How to design a quality-oriented model for assessing questions created for a formative assessment activity? How can learning analytics support teachers in the design of quality formative assessment activities?

Howland et al. (2013) introduced a five-dimensions model to evaluate how meaningful a learning technology. Based on this model, Koh (2017) studied how learning objects, when created according to Howland dimensions, promote engaging learning experiences. Koh adapts the meaningful learning dimensions to define a set of principles and good practices to develop reusable learning objects. The experiments using these learning objects showed a significant engagement of learners. Based on this prior work, I am currently supervising some works to study how Koh's recommendations can be applied to formative assessment activities with the aim of automatically assessing questions reusability (Andriamiseza, 2020). We are still working on the specification of indicators as well as on the identification of the data required to process these indicators. For instance, several metrics such as the number of submitted answers, or the length of the rationales, can be used to assess the "active" dimension which denotes the student participation in the activity. The next step will consist in developing and integrating into Elaastic both the sensors required to collect the identified data, and new features allowing teachers to reuse and share questions. The system will be facilitated to the teachers involved in the B4MATIVE! project for evaluation purposes. The objective of the experiments is to design, on the basis of the indicators, a higher-level metric reflecting the degree of reusability of a question. This metric will be extracted by analysing the correlation between the indicators and the actual reuse of questions. The institutions of the B4MATIVE! project represent an excellent experimental field, as it involves teachers from different disciplines and students of different levels.

Also, to further support teachers and help them to include quality distractors in their questions, I will explore classification algorithms in order to detect recurrent concepts associated with

incorrect arguments in students' rationales. A first approach will consist in designing dashboards to let teachers decide whether to integrate or not the detected distractors. Another approach could be to generate questions including randomised distractors extracted from previous students' answers, or to design a personalised question generator that selects distractors according to the similarity between students' argumentation components and structure, and those associated with the distractors.

Expected contributions. The results of this research plan will contribute to advance the knowledge on argumentative feedback and systems to support it. First, this work will contribute to the first French speaking data set for educational argument mining, offering new opportunities for research in this field, such as evaluation of argumentation skills and detection of students with low argumentation capacities. Second, argument mining algorithms appropriate to different disciplines and levels of education will be proposed. Third, results about the impact of quality argumentation on peers' reflection and engagement in formative assessment activities will be provided. Fourth, the results of this research plan will contribute to models and tools for automatic evaluation of question reusability. These tools will open up new opportunities for designing dashboards and tools supporting teachers in evidence-informed decision-making regarding reengineering, sharing and reuse of questions. And fifth, experiments conducted in the B4MATIVE! project will contribute to build an open repository of quality questions promoting deployment of formative assessment activities at scale, and thus leveraging active pedagogies in education.

Meaningful and explainable competence-based personalised learning

The competence-based approach is massively deployed in educational institutions, to define entire curricula as well as to design low-grained resources. Also, the need for personalisation gets stronger and stronger, as distant and hybrid forms of learning are going to be massively adopted in education to support the increasing number of students, but also to face unexpected situations such as the COVID-19 health crisis. My works have until now focused on the design of competence-based curricula on one hand (see Chapter 1), and on quality management of traces produced by learners on the other hand (see Chapter 2). I will in the mid-term perspective use my expertise in both competence-based approaches and personalisation, to investigate recommender systems featuring meaningful and explainable capabilities to generate competence-based personalised learning paths.

Hybrid AI-based recommendation

My work in this line of research will be tightly coupled with the COMPER project, whose overall objective is to promote competence-based personalised and self-regulated learning. Among the work packages I coordinate, one of them has competence-based personalisation as the main topic of research, while another focuses on competence modelling. So far, we have proposed a competence meta-model as an ontology. It introduces relations between objects that make sense from a pedagogical perspective (e.g. an object is a prerequisite of another object; an object is a lever of understanding of another object). These pedagogical relationships between objects open up opportunities to develop new recommender systems combining symbolic and machine learning approaches. A recent work by Allègre (2020) studies how hybrid artificial intelligence methods can be used for learners' knowledge diagnosis. My future plan is to explore to what

extent these same hybrid AI models can be used in competence-based recommender systems to propose personalised learning paths.

To design an hybrid AI-based recommender system, two key challenges have to be addressed: (1) the design of a recommendation process able to fully exploit semantically rich meta-models of competence, and (2) the proposal of machine learning methods able to identify and detect patterns of instructional strategies. In this research, an instructional strategy refers to the definition by Murray (2003, p. 443): "*An instructional strategy in the intelligent tutor might be: "if the current topic is conceptual and the student is doing poorly, give several examples." Alternate strategies can be created, so that the appropriate strategy can be used according to the needs of the student [...] or the pedagogical characteristics of the content being taught"*". Accordingly, my overall objective is to design a system able to take into account instructional practices of teachers, and to discover alternative instructional strategies on the basis of learners' activities on the learning systems.

Semantic-based recommendation. The need for more semantic information in recommender systems has already been claimed by the community (Al-Hassan et al., 2015). Theories such as Competence-based Knowledge Space Theory (Heller et al., 2006) could be used to process the competence meta-model (Desmarais et al., 2006; El-Kechaï et al., 2015). However, this approach only applies to hierarchical structures linking concepts through a single parent-child relation, the so-called prerequisite relation or precedence link. It does not allow to browse more complex knowledge structure such as graphs or ontologies. Also, prior competence-based recommenders have been designed on top of competence meta-models poorly featured in terms of instructional relations between competences. The systematic literature review by Yago et al. (2018) including more than twenty-five competence-based recommender systems, showed that competence modelling is mainly studied from the descriptive or organisational perspectives. Other works proposed additional semantic units such as actions, goals and resources to make competence representation and classification more comprehensive and flexible (Marques et al., 2010). But in these works, only a single composition link between competences was considered. Finally, a wide range of initiatives suggested ontologies for individualised competence management or personalisation of learning paths (Albert et al., 2011; Rosa et al., 2015; Mandin et al., 2015; Fraihat and Shambour, 2015; Wang, 2016; Miranda et al., 2017). If these works often explicitly considered competences as a set of knowledges and skills, the ontologies that have been defined include, at best, only one interesting type of relation to denote either composition between objects, or prerequisite. I could not find any proposal integrating pedagogically rich competence meta-model and therefore, I could not find guidelines or recommendations on how relations between competences, knowledges and skills could/should be used by an intelligent system. Therefore, and taking as a basis this prior work, I will investigate the following research questions: How instructional relations between competences must be used by recommender systems to recommend personalised learning paths? Do recommender systems based on pedagogically rich competence meta-models increase learning gains and learners' engagement in the learning process?

I will use an exploratory research method to address these questions. First, I will collect insights from practitioners about the pedagogical semantics of the relationships between competences through surveys and semi-structured interviews. From this, I will extract what we called the instructional strategies. That is, a set of rules following a case-based reasoning paradigm, independent from a particular domain or level. These instructional strategies, together with the competence ontology domain and the learner model including her prior knowledge on the competences, will be combined by the recommender system to generate personalised learning paths.

These learning paths are a set of resources that the learner will take via the learning environment. As a third step, the recommender system will be integrated into the project partners' learning environments, and evaluated in different authentic learning settings on four disciplines (i.e. computer science, physics, chemistry and french) at three different educational levels (i.e. elementary school, high school and university). The following experimental design will be proposed: a control group will receive recommendations of learning paths generated only considering the learner model, whereas the experimental group will be provided with recommendations of learning paths resulting from both, the instructional strategies and the learner model. Learners' engagement and learning gains, as well as well-known evaluation metrics for recommender systems (Erdt et al., 2015), will be measured and compared in both groups. Results from this experimental phase will serve as an input to improve the system and test again.

Evidence-informed instructional strategies. My research will take place in an instructional context encouraging learners to self-regulate their learning. Even if the system aims at providing them with personalised recommendations of learning paths according to the objectives they specified, learners can decline these recommended paths and design their own. We will collect traces of learners' activity in the learning environment to recover their actual learning paths (recommended or self-designed), and to update their competence levels. These data will be analysed with two purposes. First, analysing data from those students who followed a learning path recommended by the system to explore if some of the instructional strategies are more appropriate to a discipline and educational level than others. And second, analysing data from those students who defined their own learning paths to identify the most successful and unsuccessful, and to learn the higher-level instructional strategies matching with those learning paths.

While the first objective will require a simple analysis, the second objective requires a more complex approach. When the semantic approach is used for recommendation, machine learning methods are useful to infer new knowledge and improve the predictive accuracy of the recommendations (Tarus et al., 2017). What I propose in my research plan is, instead of inferring new knowledge, to infer new instructional strategies. For that, I will investigate the following research questions: What instructional strategies are the most adopted by learners and the most successful in a competence-based approach? How divergent these strategies are from those defined by teachers, and how to bridge the gaps between them?

Starting from learners' traces capturing their interactions with the learning resources, I will combine traversing graph algorithms and pattern mining techniques to detect the most frequent semantic paths. These paths will then be used to discover and learn new instructional strategies. The next steps of this empirical research will be implemented according to de Grood's cycle (1969). We will evaluate what of the identified strategies better correlate with good learning outcomes. After that, we will conduct different experiments to evaluate whether recommending the most successful strategies that emerged automatically from the learners' traces analysis leads to better learning outcomes than recommendations based on strategies proposed by the teacher. Specifically, an experimental group will receive as a recommendation learning paths automatically generated from the discovered instructional strategies, whereas the control group will be recommended learning paths derived from the instructional strategies designed by the teacher. The results of this experiment will be discussed with practitioners and educational scientists to evaluate if the strategies automatically detected should be definitely integrated into the system as another "teaching" strategy, modified before integration or not included. The general frameworks

proposed by [Aguilar et al. \(2017\)](#) or [Obeid et al. \(2018\)](#) will be the starting point to design the computational infrastructure required for this experimental setting.

The main drawback of statistical approaches is that they require a big amount of data to be reliable. Even if the recommender system will be evaluated in four different learning settings, the amount of learners' traces would be too small to infer learning paths or instructional strategies. To address the sparsity and scalability issues derived from small data samples, I will also explore collaborative filtering approaches, as recent semantic-based collaborative recommender systems implementing dimensionality reduction ([Nilashi et al., 2018](#)) or neuro-fuzzy ([Kermany and Alizadeh, 2017](#)) techniques showed efficient results. However, these approaches are based on users' ratings of items, so we need to find a measure that fits our context. For that, we will define a measure of similarity between paths taken by learners within the ontology of competences. Edge-weighted graphs are usually employed for that purpose, but the difficulty is to estimate the weights of each pedagogical relation in the competence meta-model. A given relation is not "best" or "stronger" than another one, it only gives pedagogical orientations between competences. Gradient descent algorithm could be used for this purpose.

Expected contributions. Several contributions are expected from these works. First, they should advance knowledge on systems combining symbolic and machine learning techniques in general, and on semantic-based recommender systems in particular. Second, we will provide a repository of competence-based instructional strategies for specific domains (i.e. physics, mathematics, chemistry and french), but also independent from a particular discipline. This repository will be widely available, offering the opportunity to reuse instructional strategies in any other competence-based system. And third, a set of guidelines about how to use pedagogical relations in a competence-based recommender system will be proposed. These guidelines will be based on the experimental results providing evidence-informed insights. Finally, from an educational perspective, I expect to contribute with methods and systems for researchers to help better understand learners' strategies in a competence-based environment. These methods will also provide both insights on the gaps between instructors' and learners' practices, and knowledge about how to make them converge. Long-term, I expect that these contributions could set a basis for the design of interactive tools supporting teachers in finely tuning their instructional strategies according to their discipline and/or instructional practices, and thus to contribute to the design of hybrid AI user-centred semi-automatic recommender systems.

Explainable recommender system

Another challenge regarding recommender system relates to its adoption by teachers and learners. Several researchers showed that adoption of intelligent systems is tightly coupled with the explanations provided to users; that is, people need to understand how the system works to use, trust it and, finally, adopt it in their daily practices. In the past years, and due to the increasing use of deep learning techniques in technological systems, the field of Explainable Artificial Intelligence (XAI) has gained great interest in the research community as an approach to integrate explainability and interpretability of data into intelligent systems ([Gunning, 2016](#)). Prior works on XAI have mainly focused on providing solutions to explain models and algorithms to machine learning experts or data scientists ([Spinner et al., 2019](#); [Zhang and Chen, 2020](#)). Only few efforts have been made to make these models explainable for consumers ([Arya et al., 2019](#)) or different types of AI users beyond experts ([Ribera and Lapedriza, 2019](#)). In education, differentiating be-

tween different types of users is crucial, since end-users would require a different interpretation of the IA model depending on their role. For instance, explanations for teachers should be different from those given to learners. However, works on XAI addressing this need are scarce.

As part of my future research, I plan to investigate and propose explainable models and tools that (i) take into account the different roles of educational stakeholders; (ii) can be understood by these users; and (iii) address different levels of explanation. Thus, my objective is to make intelligent educational systems more explainable. Specifically, my aim is to provide the research and practitioners communities with (1) user-centred explanations able to adapt to the heterogeneous digital literacy of the educational stakeholders, (2) explanation models transferable to actual solutions for supporting both students and teachers, and (3) interactive explanations with different levels of detail. To address these objectives, I will investigate two different research lines: open learners models and interactive explanations.

Open learner models. Open learner models (OLM) represent the main line of research explored by the TEL community to feature educational applications with explainable artificial intelligence (Conati et al., 2018). Open learner models are defined as "*learner models that allow the user (learner, teacher, peers and/or other stakeholders in the education process) to view the content of the learner model of an intelligent tutoring system or other advanced learning environment, in a human-understandable form*" (Bull and Kay, 2016, p. 294). Open learner models offer end-users the possibility to read, negotiate and edit the learners' profiles providing them with awareness about learners' cognitive, meta-cognitive or emotional states. In the specific case of educational recommender systems, OLMs have been used as a complement to the recommender interface (Abdi et al., 2020). Results of first experiments following this approach showed that integration of OLMs in recommender systems can increase learners' engagement in the system and their perceived effectiveness (Gretarsson et al., 2010). However, results also showed that, to generalise the impact of OLMs, further investigations taking into account the users' expertise level are needed. My objective is to design scalable, flexible and multi-level visualisations for facilitating users' exploration and understanding of competence-based open learner models. I will specifically tackle the following research question: What visualisations should be designed to make competence-based learner models explainable for both, teachers and students?

To address this research question, I plan to follow a design-based research methodology. I already started investigating different visualisation techniques for providing end-users with an overview of competence profiles, such as tree diagrams that can be zoomed in/out and expanded/reduced as desired. These techniques work well when visualising small hierarchical ontologies (Brancotte et al., 2018), but they hardly support scalability and cross-relations between competences. Network visualisations, or network graphs, are more appropriate for browsing structures such as competence-based OLMs, since they allow to display directed and undirected complex graph structures. Exploring how these types of graphs could be used to explain learners' competence profiles is part of my research plan. In particular, I will focus on designing a role-based OLM integrating filtering functionalities in order to visualise certain types of relationships only, or to expand and reduce certain elements. For evaluating these visualisations in terms of usability and explainability, I plan to reuse standard surveys and adapt particular instruments such as the Evaluation Framework for Learning Analytics used to measure the overall quality of visualisations (Scheffel et al., 2017). Adaptation of these existing instruments can set a starting point towards a measure for explainability. Experiments will be mainly conducted in the context

of the COMPER project in institutions ranging from elementary schools to HEIs. Diversity of institutions provide a good experimental ground for assessing the generality of the proposals.

Interactive explanations. Even if OLMs represent a relevant source of information for offering explanations to users, they have not been originally designed for explainability purposes and thus lack of dedicated functions and methods to support it. Moreover, OLMs are complex models that require learners to interpret a diversity of data and self-reflect on the information provided by the system. My future work will focus on designing a user-centred explainable AI solution that considers different groups of users and needs to provide them with actionable intelligence for facilitating decision-making (Rosé et al., 2019). Interactive explanations are a type of explanation that promote a dialogue between human users and computer agents until human are satisfied with the explanation (Weld and Bansal, 2018; Miller, 2019). Such dialogues can deliver incremental explanations that increase the level of details. My hypothesis is that interactive explanation could complement recommender systems to support users in interpreting visualisations of open learner's data, but also in understanding how the system have processed these data. I will thus especially investigate interactive explanations to increase users' support for OLMs explainability and interpretability, and address several research questions: Do explainable recommender systems based on interactive explanations increase learners' engagement in competence-based activities? What is the impact of these explanations on learning gains (in competence-based settings)? Do interactive explanations actually increase learners' understanding and confidence in judgements made by the recommender system?

Prior research regarding interactive explanations is scarce (Arya et al., 2019). However, I believe that semantic-based competence recommender systems are a good starting point to investigate the potential of interactive explanations in TEL for different reasons. First, case-based reasoning is appropriate for tracing the execution of the recommendation process, and rules and conditions are good source of information for explanation. Second, the semantic approach facilitates the process of associating interpretable hints to traces.

Interactive explanations require both an explanation model and an explanation interface. For the explanation model, I will build upon the Cooperative Principle by Grice (1975) which introduces guidelines on how to implement appropriate conversational dialogues. It includes four categories, or criteria, to make "*conversational contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which you are engaged*" (Grice, 1975, p. 45): quantity, quality, relation and manner. Arya et al. (2019) also proposed taxonomies of explanation models as decision trees for facilitating model browsing, but they are still too complex for providing non-expert users with interpretable explanations. Decision trees require end-users prior knowledge on complex concepts such as differences between the data and the model, local and global explanations, or interpretable model and post-hoc explanations. Moreover, users have to navigate through the model until they reach the explanations they need. At the opposite, in educational settings, the right explanation should be automatically delivered to the right stakeholders at the right time (Conati et al., 2019). Based on prior work by Arya et al. (2019), I will study how such decision trees can be used to guide users, step by step, towards the explanations that best fit their objectives and level of expertise.

Regarding explanation interfaces, I will build on prior works focusing on modelling human-computer interactions, and especially dialogues for explanations (Abdul et al., 2018). Works on visual analytics (Cook and Thomas, 2005) and information retrieval (Card, 1999) showed that

interaction can be a powerful mechanism when users have to discover and get insights from complex data. Also, dialogue-based systems have been designed to produce explanations according to the user knowledge and level of expertise (Cawsey, 1991). These works represent a useful basis to provide learners with general explanations such as "you should work the resources R1 and R2 because your objectives are to master the competence C"; but also with local explanations such as "you should work the resources R1 and R2 because your objectives are to master the competence C and it seems that you do not master the knowledge K and skill S, which are prerequisites of competence C". I will adopt a designed-based research methodology to conduct this research because of its iterative nature. This methodology will provide me with a systematic framework to run different iterations over the design of explanation components, their evaluation through experiments in different educational contexts for collecting feedback, and reengineering the components accordingly. Experiments will consider exposing an OLM enhanced with explanations to an experimental group, and the OLM without explanations to a control group. Differences between students' academic performance and perceptions of the system will be evaluated.

Expected contributions. The results of this research plan will advance current works on explainable AI for education, and especially in the context of competence-based approaches, even if the models and solutions proposed could be transferred to other educational settings. Also, this work will advance human-computer interaction by proposing new usable and explainable competence-based OLMs that facilitate navigation through complex graphs while integrating visual components dedicated to explanations. Also, experimental results will provide insights about to which extent explanations promote learners' engagement and facilitate understanding of the system recommendations. That is, these results will contribute to assess the impact of explanations on learners' academic performance and teachers' decision-making. Long-term, the findings of this research could contribute to address challenges on explainable models in other application domains concerned with decision-making and modelling of human behaviour.

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Glossary

- ADL** Advanced Distributed Learning. 87, 98
- AI** Artificial Intelligence. 127, 135, 136, 138, 140, 141
- ANR** Agence Nationale de la Recherche. 66, 75, 81
- CBA** Competence-Based Approach. 43, 56
- DMTF** Distributed Management Task Force. 80, 85, 95, 113
- HEI** Higher Education Institution. 41, 54–56, 64, 66, 67, 72, 74, 75, 102, 127, 140
- ICT** Information and Communication Technology. 55, 71, 72
- IEM** International E-Mi@ge. 56, 64
- KAOS** Keep All Objectives Satisfied. 89–91
- KAOS4SAM** KAOS for Self-Adaptive Monitoring. 89, 90
- KSA** Knowledge, Skill, Attitude. 66, 67, 73
- LOM** Learning Object Metadata. 42, 47, 51, 58, 61, 113, 114, 120
- LRS** Learning Record Store. 114, 115, 120
- MIAGE** Méthodes Informatiques Appliquées à la Gestion des Entreprises. 56, 64, 71
- OECD** Organisation for Economic Co-operation and Development. 53, 54
- OER** Open Educational Resource. 42, 43, 46, 47, 50, 54–62, 64, 65, 74, 75, 125
- SLA** Service Level Agreement. 78, 97
- STEM** Science, Technology, Engineering, and Mathematics. 45, 46, 103, 119, 122, 129
- SUS** System Usability Scale. 110, 119
- TEL** Technology-Enhanced Learning. 41–44, 46, 48, 49, 51, 52, 55, 57, 103, 110, 125–127, 139, 140
- TPS** Think-Pair-Share. 45, 49, 103–106, 108, 110, 122
- VLE** Virtual Learning Environment. 55, 61, 62, 64, 108

VRL Virtual and Remote Laboratory. 104, 112, 113, 120

WBEM Web-Based Enterprise Management. 85, 93, 94

xAPI Experience API. 88, 114, 115, 120