Designing Serious Games, Mobile Learning and Extended Reality Applications for and with teachers

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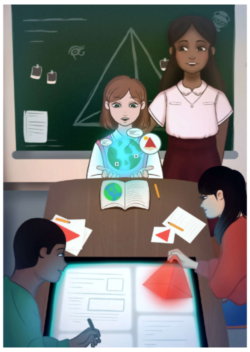
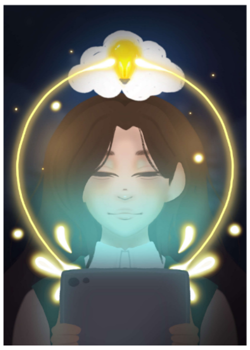
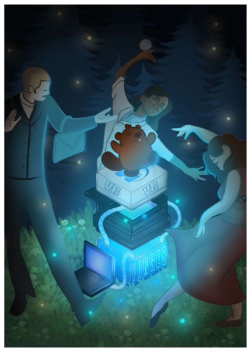
Open Educational Resource





Abstract

This manuscript presents our main contributions in Technology-Enhanced Learning (TEL) and in particular how Serious Games, Mobile Learning and innovative Human-Computer Interactions, can be designed and used to improve learning at all levels, from pre-school to vocational training.

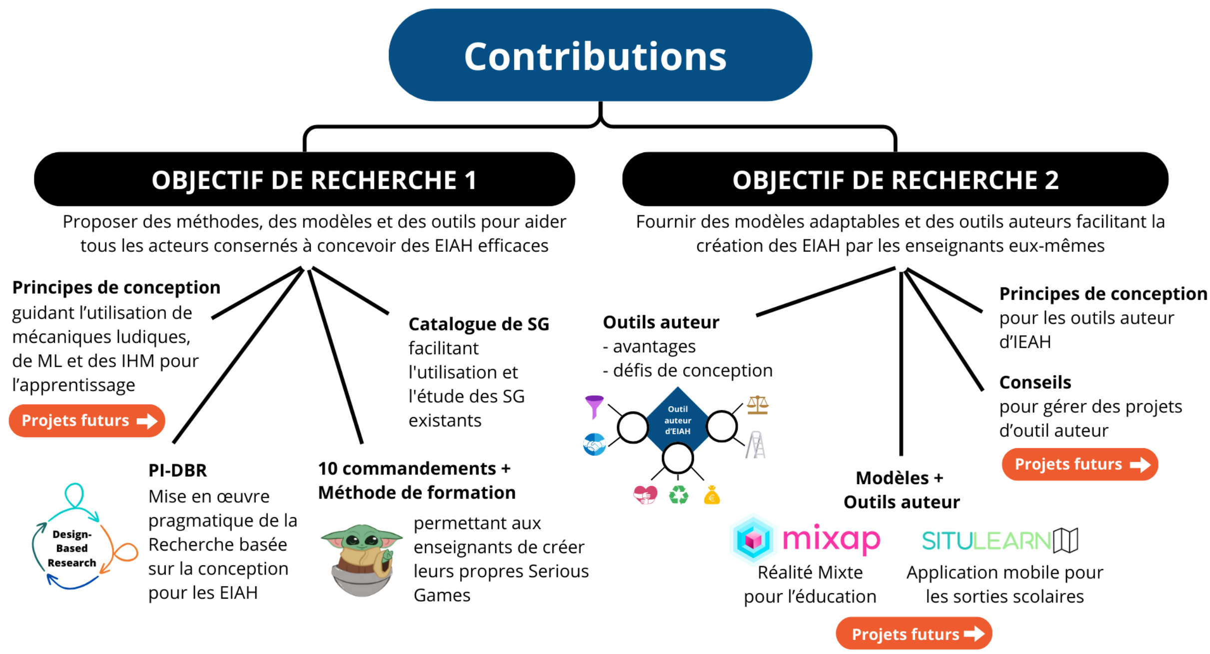
We have addressed two main challenges. First, we provide methods, models and tools to help all the necessary actors, including teachers, game designers and developers, to design effective TEL systems. Through multiple projects, tested in classrooms, we identified several design principles that contribute to the research community. Our second challenge is to facilitate the creation of TEL systems by teachers themselves and thus increase their acceptability and use in schools. In particular, we developed adaptable models and authoring tools to help teachers create two types of TEL systems: Mixed Reality educational activities and geolocated smartphone applications for field trips.

On the basis of these contributions, a research plan is presented for the future. In the short-term, I plan on exploring ways to encourage collaborative situated learning. In the middle-term, I plan to continue working on authoring tools with European partners. And, in the long-term, I would like to pursue a more ambitious challenge which is to increase the impact of TEL research in French schools. This implies proposing open-source software architectures to encourage collaboration among researchers, education technology companies and teachers.

Résumé long en Français

Ce manuscrit présente nos principales contributions dans le domaine des Environnements Informatiques pour l'Apprentissage Humain (EIAH). Dans le premier chapitre, nous présentons brièvement l'historique de ce domaine de recherche. Il s'agit d'un domaine qui est, par nature, multidisciplinaire puisqu'il repose sur des théories d'apprentissage et d'enseignement (issues des sciences humaines et sociales), mais aussi sur des innovations techniques (issues de l'informatique). Notre recherche contribue à trois sous-branches des EIAH : les Serious Games (SG) (jeux sérieux), les applications mobiles (ML) et les Interactions humain-machine (IHM) innovantes pour l'apprentissage. Ces branches soulèvent plusieurs défis de recherche communs : une conception complexe et multidisciplinaire (impliquant des acteurs qui ne sont pas toujours disponibles), des coûts de production élevés et la nécessité de démocratiser l'utilisation de ces outils à l'école. Nous nous concentrons donc sur deux objectifs de recherche:

- **Objectif 1 : Fournir des méthodes, des modèles et des outils pour aider tous les acteurs concernés à concevoir des EIAH efficaces.**
- **Objectif 2 : Fournir des modèles adaptables et des outils auteur afin de faciliter la création des EIAH par les enseignants eux-mêmes et ainsi augmenter l'acceptabilité et l'utilisation de ces outils dans les écoles.**



Nos projets de recherche, visant ces objectifs, ont tous été menés avec des collègues en sciences humaines et sociales. Nos EIAH ont également été conçus et testés en collaboration avec des enseignants pilotes et leurs apprenants.

Le deuxième chapitre rend compte de nos efforts pour atteindre notre premier objectif de recherche. Nous proposons d'abord plusieurs principes de conception qui permettent de mettre la technologie au service de la pédagogie. Ces principes sont issus de nos projets de recherche :

- TurtleTable(t) : utilisation de mécaniques de jeu et d'objets tangibles pour favoriser un apprentissage collaboratif des bases de la programmation informatique.
- SMART-Fractions : utilisation de mécaniques de jeu et de Réalité Mixte pour enseigner aux enfants à placer une fraction sur une droite graduée.
- TGRIS : utilisation d'un simulateur de Réalité Virtuelle pour aider les professionnels à gérer leurs émotions dans des situations compliquées.

Sur la base de notre expérience, nous proposons **une méthode pour faciliter la conduite de ce type de projet de recherche en EIAH** avec des usages numériques innovants. Cette méthode, nommée PI-DBR, est une mise en œuvre pragmatique de la Recherche basée sur la conception (Design-Based Reaserch, DBR) avec une implication progressive des chercheurs et des enseignants.

De plus, nous proposons **une méthode de formation et 10 « commandements » pour aider les enseignants à créer leurs propres Serious Games** (numériques et non numériques) sur mesure, avec les ressources et le personnel qu'ils ont à disposition. Ces propositions ont été développées et raffinées au cours de sept années d'animation de la formation professionnelle Ludifik'action. Plus de 104 enseignants et ingénieurs pédagogiques ont participé à cette fomation qui a abouti à la création de plus de 32 Serious Games actuellement utilisés dans des établissements universitaires, partout en France.

Pour finir, nous proposons **JEN-Planet, un catalogue de Serious Game**, capable de se mettre à jour automatiquement, pour aider les enseignants et les chercheurs à trouver des Serious Game existants.

Le troisième chapitre rend compte de nos efforts pour atteindre notre deuxième objectif de recherche, à savoir comment fournir des modèles adaptables et des outils auteur afin de faciliter la création d'EIAH par les enseignants eux-mêmes. Nous soulignons, tout d'abord, les cinq principaux avantages des outils auteur : 1) Ils couvrent un large éventail de besoins et peuvent donc être utilisés par un grand nombre d'enseignants, 2) Ils permettent la conception collaborative d'EIAH et la création d'une communauté d'utilisateurs, 3) Ils produisent des EIAH que les enseignants peuvent s'approprier puisque ce sont ces derniers qui apportent leur propre contenu, 4) Ils produisent des EIAH réutilisables, car les enseignants peuvent modifier et mettre à jour le contenu. Et pour finir, 5) les outils auteur permettent de produire des EIAH bon marché, car les enseignants n'ont pas besoin d'autres ressources ou de personnel qualifié.

Cependant, les outils auteurs présentent deux défis de conception majeurs. Tout d'abord, il est difficile de créer un outil auteur offrant de nombreuses fonctionnalités qui soit à la fois simple et rapide à utiliser. De plus, les enseignants ont une tendance naturelle à utiliser les EIAH simplement pour recréer leurs paradigmes d'enseignement habituels. Il est donc difficile de les encourager à tenter de nouvelles méthodes d'enseignement et ainsi utiliser ces outils à leur plein potentiel pédagogique.

Nous tentons de trouver des solutions à ces défis dans le cadre de deux types spécifiques d'EIAH. Le premier cas est celui de la création **d'activités pédagogiques intégrant de la Réalité Mixte**. Nous proposons des modèles originaux d'activités qui conviennent non seulement à tous types de disciplines, mais également à tous publics, de la maternelle à l'université et également un outil auteur très simple (MIXAP). Ces éléments ont été co-conçus et testés avec 19 enseignants pilotes. Le deuxième cas concerne la création **d'applications mobiles pour**

l'apprentissage situé. Nous proposons un modèle de jeu éducatif mobile qui est extensible et adaptable à de nombreuses sorties, ainsi que plusieurs outils auteur qui permettent aux enseignants de créer leurs propres applications mobiles géolocalisées. Ces propositions, issues de trois projets de recherche consécutifs, qui se sont déroulés sur près de 10 ans, ont été co-conçues et validées par plus de 21 enseignants et 2000 apprenants. Le dernier de ces outils auteur, SituLearn, est maintenant assez mature, robuste et ergonomique pour être transféré au grand public et utilisé non seulement par les écoles, mais également par les musées et les offices de tourisme.

Enfin, sur la base de nos expériences, nous proposons **plusieurs principes de conception qui peuvent guider ceux qui souhaitent créer un outil auteur** en EIAH ainsi que des **conseils pour la gestion de tels projets de recherche**.

Dans le dernier chapitre, je présente les trois directions principales de mon futur programme de recherche.

À court terme, j'ai l'intention d'identifier davantage de principes de conception concernant l'utilisation d'IHM innovantes pour l'apprentissage collaboratif. Ce travail a déjà été entamé en collaboration avec mon dernier doctorant, qui est actuellement dans sa troisième année de doctorat.

À moyen terme, je poursuivrai mon travail sur les outils auteur. Tout d'abord, j'aimerais continuer le projet MIXAP au niveau européen et notamment explorer le potentiel de l'Intelligence Artificielle générative pour l'assistance à la création de contenu pédagogique. J'aimerais également développer un nouvel outil auteur qui permettrait la création d'activités de réalité virtuelle ou augmentée à utiliser dans le cadre de la formation professionnelle.

Enfin, à long terme, j'aimerais relever un défi plus large : réduire le fossé important entre nos projets de recherche et l'utilisation de la technologie dans les écoles françaises. Pour ce faire, je proposerais des architectures qui fédèrent des forges de logiciels libres afin d'encourager la collaboration entre les chercheurs, les entreprises Edtech (technologies de l'éducation) et les enseignants. J'ai déjà commencé à explorer plusieurs pistes grâce à mes récents contacts au Ministère de l'Éducation Nationale.

Acknowledgements

First, I would like to express my gratitude to the esteemed **jury members** of my accreditation diploma: Elise LAVOUE, Wendy E. MACKAY, Roland KLEMKE and Baltasar FERNANDEZ MANJON. They are all very busy researchers and I am very honored that they took some of their precious time to read my manuscript, write a report and travel to Laval for my oral defense. Their recognition of my work made me very proud of all that I have accomplished so far and their constructive feedback was very useful to help me improve the way I present my research.

I would also like to thank **my family** for their love and support.

I'm glad my parents, Daniel and Wendy, passed on their thirst for knowledge and their values of hard work and commitment. I have fond memories of spending hours in the house office, feeding sheets of paper to the printer, one at a time, as it processed the huge manuscript of my mothers' second PhD. I also remember the strange challenges my father used to present me with, such as calculating the length of the wound-up coil, which involved math that was clearly too advanced for my age. Looking back, I think I was clearly destined to do academic research and I'm definitely hooked on it now ! My little sister, Nora, always inspires me with her numerous artistic projects carried out in parallel to an impressive professional career as an architect. Both her and my mother were very helpful proofreading my manuscript. If you still spot some typos, just bear in mind it was much, much worse before! My brain is just not hardwired for spelling ;) My little brother, Deny, sadly not with us anymore, is still very present by my side. He pushes me to make the most out of life because you literally do not know when it will end.

I thank my partner, Yannick, who has put up with my occasionally excessive enthusiasm for research, over the past two decades. He has always been supportive of my career choices and followed me, without question, when I got a Posdoc in Stockholm and then an associate professor position in Laval, despite it not being ideal for his career. After experiencing research firsthand during his Master's degree in Nurse Practitioning, he now thinks I'm completely insane but this makes his support even more remarkable.

Our two boys, Liam and Sacha, were very patient throughout these past few months while I spent many evenings and weekends writing and preparing for this accreditation diploma. Liam, who is now eight, believes that my "book" is going to make me famous. He also told me the drawings were too babyish which is probably good editing advice. Sacha, six years old, considers it was a waste of time and wishes I had spent more time cuddling him. Kid number three, still in my belly, has also supported me throughout the process. Initially, subtly, by urging me to complete the manuscript before she is born and now, more vigorously, by kicking and keeping me awake at night to ensure I review my presentation, just in case I overlooked something.

Furthermore, I would like to thank **all the colleges I have worked with** since the start of my doctoral program.

I am especially thankful to have had the opportunity to work alongside Sébastian GEORGE. He was my PhD co-supervisor when we were both in the LIESP lab in Lyon. A few years later, we were both appointed positions at LIUM in Laval, with Sébastien assuming the rank of full professor and myself as an association professor. His advice and encouragement, throughout these years were very valuable. It was only natural for me to ask him to serve as the guarant of my accreditation diploma. It's been a pleasure working with him and he still managed to impress me by his kindness, diplomacy and leadership qualities. I already said this in my PhD acknowledgements, but he is, more than ever, my professional role model.

It was also a great pleasure and inspiring experience collaborating with my PhD students: Aous KAROUI, Wielfrid MORIE, Sofiane TOUEL and Sebastian SIMON. A large proportion of the work presented in this manuscript was possible thanks to their commitment.

Over the past few years, I have collaborated with numerous teachers from preschool, middle school, high school, university and even vocational training. Their enthusiastic participation has given me a deep sense of purpose and fulfillment in my work. They welcomed us with open arms into their classes so we could observe how they teach and worked with us, for free, to design and test new tools. How many of us would do that? I was genuinely impressed by their patience, their passion and their remarkably crafty ideas to use technology for educational purposes. Witnessing them using the tools we co-designed, makes me feel like I am doing something useful for society.

Finally, I would like to thank all the colleges of the faculty at LIUM and Le Mans University: my research colleagues who put up with my sometimes original communication actions, my teaching colleagues of the IUT's computer science department, who did not complain in the least, each time I needed to adjust my teaching hours and responsibilities for maternity and research leaves. I would also like to extend my thanks to the administrative, technical and custodial staff. They have all contributed to creating a friendly and favorable work environment that has been highly productive for me these past 10 years.

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Part I

Curriculum Vitae

Iza MARFISI-SCHOTTMAN

Born	April 4th, 1985, Laxou, France, French and American nationality
Marital Status	Married (Pacs), 2 children
Work Address	IUT de Laval, Département Informatique 52 rue des Docteurs Calmette et Guérin 53020 LAVAL Cedex 9, France Phone : +33 7 81 88 18 52 Email: iza.marfisi@univ-lemans.fr Web: https://lium.univ-lemans.fr/team/iza-marfisi/
Pers. Address	33 chemin de la Lande 53970 L'huisserie

1 Academic Degrees

2013	**Qualification to apply to associate professor positions** Section 27: Computer Science
2012	**PhD in Computer Science** INSA de Lyon, Lyon LIRIS Lab – computer science lab in image treatment and information systems Title: Methodology, Models and Tools for Designing Learning Games National merit scholarship
2008	**Master's degree in math and computer science** University of Lyon, France Specialized in computer science research

2 Professional Experience

2013 - present	**Associate Professor** (Maître de Conférences) in Computer Science Le Mans Université, IUT de Laval, LIUM Lab, Laval, France
2012 – 2013	**Postdoc Researcher** Swedish Institute of Computer Science, Mobile Life KTH Royal Institute of technology, Stockholm, Sweden FP7 Marie Curie co-fund fellowship, project ABCDE (GA ID: 246016)
2012 – 2012	**Teaching and research assistant** (ATER) in Computer Science LIP6 lab, UPMC University, Paris, France
2008 – 2012	**PhD student in Computer Science** LIRIS Lab, Lyon, France Teaching assistant (Monitrice) in Computer Science INSA de Lyon, Computer Science departments and International Master's degree of Lyon University, Lyon, France

3 Research Activities

My research is the field of Technology-Enhanced Learning (TEL). My projects cover a large variety of educational fields from pre-school to vocational training. My research program aims to overcome two main challenges. The first is to find more efficient ways of teaching by designing innovative TEL systems with teachers and experimenting them in class. My projects focus on Learning Games and innovative Human-Computer Interactions such as Mixed Reality, Virtual Reality and Tangible objects. The second challenge is to develop methods and authoring tool to enable teachers to create their own custom TEL systems.

Type of communication	**Number**
Edited books	4
International journals with editorial board	5
National journals with editorial board	2
Book chapters	2
International conference with proceedings and program committee	21
National conference with proceedings and program committee	11
Short papers, workshops and demos	14
PhD thesis	1
Master thesis	1
Dataset	1
TOTAL	**62**

Here is the list of my publications. When available, the rank of the publication according to SCIMAGO, CORE or ATIEF's classification systems is provided. ATIEF is the French scholar society for TEL and I have been a member since 2008. All my publications are Open Access on HAL open access library.

3.1 List of publications

Edited books

Mario A., Manuel G., Marfisi-Schottman I., Giusseppe C., Franck D., Special issue on Artificial Intelligence for Education, Frontiers in Education, 2023, in press. Q2 SCIMAGO

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3.2 Software registration

2023	**The Magic Cauldron**, a Mixed Reality Game to learn fractions IDDN.FR.001.200020.000.S.P.2023.000.10000
2023	**Quizz App**, a digital version of the Serious Game The Potions Workshop IDDN.FR.001.200021.000.S.P.2023.000.10000
2022	**MIXAP**, authoring tool to create educational activities with Augmented Reality IDDN.FR.001.500020.000.S.P.2022.000.10000
2022	**SituLearn**, authoring tool to create smartphone applications for educational field trips, museums and cultural centers IDDN.FR.001.500021.000.S.P.2022.000.10000

2021	**TurtleTablet**, a collaborative game to learn the principals of computer programming IDDN.FR001.380005.000.S.P.2021.000.10000
2018	**Jem-Inventor**, authoring tool to create geolocated smartphone applications for educational field trips IDDN.FR.001.080005.00.S.A.2020.000.10000
2015	**LEGADEE**, a collaborative tool to design Serious Games IDDN.FR000.490009.000S.0.2015.000.10000

3.3 Invited talks and keynotes

2023	**EATEL summer school keynote** "Authoring tools for Technology-Enhanced Learning: giving the creative power back to teachers!", 120 participants, La Manga, Spain.
2023	**Talk at MIT STEP Lab**, "Serious Game and Innovative HCI for learning", Boston, USA
2023	**Talk at DOMUS Lab**, "Design methods for authoring tools", Sherbrooke, Canada
2022	**Talk at LINE Lab** "Design of Serious Games and Extended Reality applications for and with teachers", Nice, France
2022	**Conference keynote** "10 commandments of the Serious Game Padawan", teacher training seminar on teaching with games, 200 participants, Rennes, France
2021	**Talk at Deeptech**, research & entrepreneur event organized by Bpifrance, 400 participants, Paris, France
2020	**Talk at CHU Nantes** research seminar "TGRIS – Teacher-Guided Realistic Interview Simulator: a tool and a method", Nantes, France
2019	**Talk at CIREL lab** "TurtleTable: learning the computer programming with tangible objects", Lille, France
2018	**Conference keynote** "How to help teachers create their own games for their classes" Symposium on alternative higher education, 300 attendees, UBL, Rennes, France

3.4 Research projects

2021 – present **MIXAP: Authoring tool for educational Mixed Reality Applications**

https://mixap-lium.univ-lemans.fr/

Funding institution: Rising Star grant of the Pays de la Loire region, France

Budget: (Le Mans University only): 126 k€

Partners: CREN (Le Mans) and Réseau Canope (Laval)

Description: This project aims at designing authoring tools for educational Augmented Reality applications and measuring the impact of such a tool on teachers and learners. This project is lead in close collaboration with 10 pilot teachers.

My role and contributions: Principal Investigator, Le Mans University. After obtaining the funding from the rising star program, I set up a partnership with the Réseau Canopé, a national teacher training association. They were in charge of finding pilot teachers in various fields of education. I also involved a researcher in educational science for CREN. I set up several meetings with all the pilot teachers to understand their needs and co-design the educational Augmented Reality activity models. With the Post-doctorate I hired, we developed the MIXAP authoring tool and tested it in all 10 classes.

2021 – present **SituLearn: Authoring tool to help teachers create mobile games for field trips**

https://situlearn.univ-lemans.fr/

Funding institution: Funding institution: young researcher grant of the French national research agency (ANR JCJC)

Budget: (Le Mans University only): 222 k€

Partner: CREN (Nantes)

Description: This project aims to help teachers enrich their educational field trips with mobile applications. The models and tools that we offer apply to all the fields of education that require situated learning (History, Botany, Geology, etc.) from kindergarten to vocational training. They promote fun and collaborative learning experiences. The project involves nine pilot teachers.

My role and contributions: Principal Investigator, Le Mans University. After obtaining the funding with a team of researchers in computer science and social sciences, I found pilot teachers who were used to doing educational field trips. I organized several meetings and work sessions to identify their needs and create a generic education model for this type of outings. This model was inspired by those created during the former ReVeRIES project and Jem-Inventor, my first PhD student's project. I also hired a new PhD student, Sebastian SIMON, to design tools to promote collaborative learning during field trips. This led to exploring multiple technical solutions to add digital augmentations to a paper map, including one in collaboration with the LAUM acoustics lab. I also initiated a partnership with the department archives, the local Manas art museum and the Laval tourism center. In total, this project involves 11 researchers, 9 pilot teachers and 19 students so far.

2020 – 2023 **SMART-Fractions: Mixed Reality game for learning fractions**
https://smart-fractions.univ-lemans.fr/
Funding institution: funding from the Plaisir Math Company
Budget: (Le Mans University only): 9 k€
Partners: Plaisir Math Company
Description: This project aims to investigate the effectiveness of Mixed Reality and games to learn fractions, one of the most complicated and stressful subjects for children.
My role and contributions: Principal Investigator, Le Mans University. I obtained private funding from the Plaisir Math Company to design and develop *Quizz* App, a digital extension of their board game, *The Potions Workshop*, for learning fractions. After conducting the state of the art and identifying the difficulties related to learning fractions with pilot teachers, we designed a Mixed Reality game: *The Magic Cauldron*. I co-supervised Sofiane TOUEL, a PhD student on this project. When the company abandoned the project for financial reasons, during the COVID pandemic, I found ways to improve the game's interface design, create the game material and also to test this game with local schools (more than 200 students).

2016 – 2021 **TGRIS: Teacher-Guided Realistic Interview Simulator**

https://lium.univ-lemans.fr/tgris/
Funding institution: Atlanstic 2020 funding
Budget: (Le Mans University only): 12 k€
Partners: CREN (Nantes), Lab-sticc (Brest)
Description: This project aims at providing training methods to help professionals deal with stressful and emotional situation. We designed a Virtual Reality simulation tool, configured and piloted by the trainees themselves.
My role and contributions:Principal Investigator, Le Mans University. I initiated the project after discussing with and college from CREN who was in charge of the training program of educational counselors in the Nantes academy. After conducting a state of the art, I contacted a colleague for Lab-Sticc who was working on embodied conversational agents. With the help of a master's student, we created TGRIS by adding an interface to configure and pilot the agent in real time. All the content for TGRIS was provided by a group of educational counselors, after analyzing and extracting "problematic situations" from real interviews they had led. We tested the tools every year, for four years, during their annual training program and improved it along the way.

2017 – 2020 **TurtleTable(t): A collaborative game to learn the basics of computer programming**

https://turtletablet.univ-lemans.fr/
Funding institution: IUT de Laval internal funding
Budget: (Le Mans University only): 6 k€
Partners: Volumique Company
Description: This project aims at investigating the use of tangible objects to encourage collaboration. We developed four versions of the TurteTable game for computers, interactive tabletops and tablets with and without tangible objects.
My role and contributions: Principal Investigator, Le Mans University. One of my interns developed a framework capable of detecting the rotation and movements of a tangible object on interactive tabletops. I used this code to create TurteTable, a collaborative game for learning the basics of computer programming. Collaboration is encouraged through the game mechanics but also through the fact that the players need to manipulate their own tangible object to win the game. After the first encouraging experimentations with four classes, I obtained internal funding to create TurteTablet: a new modified version of the game for tablets, a device that is already available in many schools. I set up a partnership with the Volumique Company who had a framework for recognizing objects on tablets and redesigned the game to fit a smaller screen. I set up more experimentations with this version that is currently still used in schools.

2017 – 2020 **ReVeRIES: Fun, interactive and educational plant recognition on smartphones**

https://reveries-lium.univ-lemans.fr/
Funding institution: ANR
Budget: 643 k€
Partners: LIRIS (Lyon), EVS (Saint-Etienne), LISTIC (Chambery), IRHS (Angers)
Description: This project aims at investigating the use of game mechanics and mobile applications to help citizens learn about the plants that surround them. The applications uses semi-automatically recognition of tree species from picture the users take of leaves, flowers or bark. The secondary objective was to collect data for participatory inventories.
My role and contributions: Researcher, LIUM. I was in charge of a WP related to designing the authoring tool to create fun educational outings. I set up brainstorming sessions with teachers and natural park owners to understand their needs and propose generic models. I also helped set up the experimentations.

2014 – 2018 **JEN.Lab: Tools and methods for designing digital epistemic games**

http://jenlab.fr/
Funding institution: ANR
Budget: 525 k€
Partners: icar (Lyon), ifé (Lyon), LIRIS (Lyon), Symetrix Company
Description: This project aims at proposing models and methods to facilitate the design of digital epistemic games. These games place the learners in authentic situations where they need to use a variety of professional skills. The project created three of these games in various domains: for professional training, for civic education in middle school and for technical education in high school.
My role and contributions: Researcher, LIUM. I proposed an extension of the model designed during my PhD to help design the epistemic game scenarios. I also helped a PhD student design the toolkit to facilitate the development of such games.

2012 – 2013 **CrowdFlash: A participative light and sound show using mobile phones in crowds**

http://free.iza.free.fr/research_CrowdFlash.php
Funding institution: KTH, Stockholm, Sweden
Budget: 3 k€
Description:This project aims at creating an immersive and collective emotional experience where each person in the audience plays an important role. CrowdFlash uses a peer-to-peer opportunistic network to spread information among mobile phones in the audience.
My role and contributions: Principal Investigator, Mobile Life Lab (Stockholm). I was in charge of designing and developing a mobile application based on an opportunistic network designed by my supervisor. After studying the behavior in concerts and sports stadiums, I proposed an interaction model and a multi-agent algorithm to create an immersive interactive experience. After obtaining internal funding from KTH, I was also in change of a Master's student.

2012 – 2013 **Generic Serious Games: Enabling teachers to design Serious Games in any field**

http://free.iza.free.fr/research_GenericSeriousGame.php
Funding institution: Investissements d'Avenir, French government
Budget: 355 k€
Partners: UNF3S, UNIT, UNJF, UVED, UNISCIEL, AUNEGE (group of French universities), Editions Lavoisier, Strass and Kokopelli companies (France)
Description: This project aims at designing a generic model that allows university teachers to create their own Learning Games with very little or no help from developers and graphic designers.
My role and contributions: Post-doctorate researcher, LIP6 (Paris). I was in charge of identifying the needs of the six French universities by leading group meetings and brainstorming sessions. I then proposed a Serious Game model based on case studies, which is a standard teaching method. This model was designed in collaboration with university teachers in various fields: medical care, law, engineering and finance.

2009 – 2011	**Learning Game Factory**: Reusing parts or entire Learning Games http://free.iza.free.fr/research_LearningGameFactory.php Funding institution: FEDER, European funding Budget: 1188 k€ Partners: SYMETRIX (Lyon), DAESIGN (France), SBT (France), LES TANUKIS (France), GENEZIS (France), LIG lab (Grenoble), ESC lab (France) and SYSCOM lab (France) Description: This project aims at providing an environment for the design, development, dissemination and reuse of entire Learning Games or parts of them. My role and contributions: PhD student, LIRIS (Lyon). My contribution to this project was to propose the LOMFR-LG metadata, which facilitates the identification and reuse of Learning Game software components.

3.5 Organization of scientific events

2023	**General chair of the LIUM Edtech conference** One day of workshops and conferences for researchers, teachers and the general public, 120 participants, laval, France
2023	**Program co-chair of the Workshop on authoring tools for Augmented Reality** IHM conference, Troyes, France
2022	**Program co-chair of the winter school on research methods in TEL** Leysin, Switzerland
2021	**Program co-chair of the Games and Learning Alliance international conference** La Spézia, Italy
2020	**General Chair of the Games and Learning Alliance international conference (GALA)** Online in the Laval Virtual World, including an interactive exhibition and a serious game competition, 500 attendees
2019	**Competition Chair of the Games and Learning Alliance international conference** Athens, Greece
2018	**Competition Chair of the Games and Learning Alliance international conference** Palermo, Italy
2011	**Organization committee of the international Game-Based Learning summer school** Autrans, France
2009	**Organization committee of the IHM conference** Grenoble, France

3.6 Institutional responsibilities

2022 – present	Elected vice director of research of the Claude Chappe Computer Science Institute
2021 – present	Elected member of the international Serious Game Society board
2021 – present	Elected member of IKIGAI's board, association that promotes Educational Games
2021 – present	Elected to the LIUM's laboratory council
2016 – present	Head of communication for LIUM's IEIAH team Website, social media, encouraging internal and external communication
2016 – 2021	Elected to Le Mans University's Research commission
2013 – 2018	Responsible for the team's bi-annual article writing workshops Encouraging article writing, organizing internal reviewing process
2014 – 2017	Organization of monthly scientific seminars for the team Contacting participants, planning their trip, filming, communicating (23 in all)
2010 – 2012	Head of communication for the Doc'Up PhD student association Designing comic trips, posters, flyers, logos to promote projects and events

3.7 Scientific societies

2020 – present	Member of the EATEL Society
2018 – present	Member of the Serious Game Society
2008 – present	Member of the ATIEF (French research society on Technology Enhanced Learning)

3.8 Program committee and review

Journals	International Journal of Serious Games (IJSG) Review committee member since 2018 Multimedia Tools and Applications Reviewer: 2021 IEEE Transactions on Learning Technology (IEEE TLT) Reviewer: 2021 IEEE Access Reviewer: 2018 Interactive Design and Architecture Journal Reviewer: 2019 International journal on Virtual Reality (IJVR) Reviewer: 2019 TREMA Reviewer: 2014

Int. Conferences	Games and Learning Alliance Conference (GALA) Program committee member since 2018 European conference on Technology Enhanced Learning (EC-TEL) Reviewer: 2014, 2018 Virtual Reality International Conference (VRIC) Reviewer: 2013, 2014, 2019 European conference on game-based Learning (ECGBL) Reviewer: 2014 International Conference on Computer Supported Education Reviewer: 2015 Colloque International Game Evolution (CIGE) Reviewer: 2022, 2023 The Hawaii International Conference on System Sciences (HICSS) Reviewer: 2014
Nat. Conferences	Environnement Informatique pour l'Apprentissage Humain (IEAH) & RJC-EIAH Program committee member since 2016 Ludovia conference Program committee member since 2018

3.9 Member of PhD defence jury

2021	Wilfried MORIE, LIUM Co-supervisor: July 1st
2020	Damien BRUN, LIUM/TELUQ Examiner: November 18th
2018	Aous KAROUI, LIUM Co-supervisor: September 21st

3.10 Scientific expertise

2022, 2023	Evaluation of a RIPEC bonus Le Mans Université
2022 – present	Follower committee of Jérome HERNANDEZ's PhD thesis Sorbonne Université
2020 – present	Follower committee of Sebastian GAJEWSKI's PhD thesis Université de Lille
2017 – 2020	Follower committee of Quentin COULAND's PhD thesis Le Mans Université
2020	Evaluation of an Hors Class graduation Le Mans Université
2017	Evaluation of a master's thesis TELUQ, Quebec, Canada
2014, 17, 19	Evaluation of an ANRT/CIFRE project proposal

3.11 Scientific delegation

2018	Participation in the RFI Ouest Industrie Créative delegation to Quebec, 10 researchers selected from the Western region of France

4 Teaching Activities

Recent and ongoing classes

I have mainly been teaching at the Computer Science department of the Laval IUT since 2013. This technical school only provides Bachelor degree type classes. I also teach a few hours in the computer science master's degree at Le Mans Université (1 hour from Laval). In 2020, I also started tutoring student projects at the ENSIM engineering school in Le Mans. Furthermore, since 2017, I've been involved in the creation of a partnership between the IUT and the Law School in Laval for which I give several classes. Finally, for the past 6 years, I've been running the Ludifik'action professional training course that is hosted in two universities: Le Mans and Rennes.
I teach approximately 210 hours per year, except for years with maternity leaves (2015, 2017) and reduced teaching hours given for research projects. In 2022, I obtained two 6-months CRCT teaching leaves, one from my university and one from the University National Council (CNU). The SituLearn ANR JCJC project also provides the Principal Investigator (me) with 3 years of reduced (50%) teaching hours.
The table below summarizes the courses given since 2013.

Training program	**Level**	**Course**	**L**	**P**	**H**	**T**
Computer Science dept., Laval IUT	1st - 2nd year	Mobile programming	■	■	■	
		Object Oriented Modeling		■	■	
		Advanced Data Bases		■	■	
		Tutored project				■
		Internship				■
Computer Science Faculty, Le Mans	5th year	Serious Game design		■		
ENSIM engineering school	5th year	Tutored project				■
Law School, Laval campus	1st - 3rd year	Basics of Computer Science	■		■	■
Le Mans et Rennes Université	Prof. training	Ludifik'action	■			■

L: lecture – P: practical session – H: hands-on lab session – T: tutoring

2014 – present **Mobile programming. Coordinator**
Hours: 4h. L, 30h. P, 48h. H (50 students)
Content: Android development, access to smartphone sensors, responsive interface design, data bases.

2015 – present **Object Oriented Modeling. Coordinator**
Hours: 9h. P, 30h. H (50 students)
Content: UML diagrams, tools to create diagrams, plugins to automatically generate diagrams, tools and methods for code documentation.

2013 – present	**Tutored project** Hours: 15h. of tutoring (12 students) at Laval IUT + 15h. (15 students) at ENSIM Role: providing a project subject and a client specification document, tutoring during the development and evaluation of the documents and final product.
2013 – present	**Internship** Hours: 20h. of tutoring (4 students) Role: regular follow-up during the internship, visiting the company, evaluating the final report and the presentation.
2017 – present	**Basics of Computer Science. Coordinator** Hours: 2h. L, 5h. P, 2h. T (20 students) Content: Basics of computer programming and languages, computer hardware, information transfer through Internet, demystifying Artificial Intelligence, hand-on project in collaboration with the computer science students from the Laval IUT.
2017 – present	**Ludifik'action. Coordinator** Hours: 14h. L, 18h. T (9 to 20 trainees) Content: Basics of game design, Serious Game design, creation of game material in collaboration with a FabLab, custom advice and follow-up sessions at the trainees school, experimentation of the designed Serious Game prototype in class.
2015 – 2020	**Serious Game design** Hours: 5h. of practical sessions (16 students) Content: Serious Game testing and evaluation, Serious Game design methods and tools, creation of a Serious Games.
2013 – 2014	**Advanced Data Base** Hours: 27h. P, 18h. H (50 students) Content: advanced SQL.

Innovative teaching methods

I take it upon myself to try innovative teaching methods and tools whenever it is possible for all of my courses. Even though this is very time consuming, I believe this is essential to provide the best quality teaching and is it also closely related to my research subject.

2015 – present **Gamification**
Object Oriented Modelling is perceive as boring and useless by students in computer science. It is therefore a very challenging class. When I started teaching it, I therefore added several game mechanics and transformed the classic lectures into practical sessions where students work in groups. I also styled the Moodle online course and the slides to create a coherent gaming experience. Furthermore, I use a smartphone application to give and receive custom-made trophies. This application was designed by a colleague for the KatasTROPHYk project. The trophies promote good behavior in class and can be exchanged against advantages (e.g. choosing the session they will be evaluated on, peeping at least year's exam) and tokens that can be used in the arcade machine set up in the computer science department.

2017 – present **Classes in English**
After discussion with my colleagues, I decided to give the course on Object Oriented Modelling entirely in English. I was contacted by Le Mans Université to present my experience in a video and write a report. The objective was to encourage other teachers to do the same. Both are accessible online.

2013 – present **Online videos and Open Educational Resources**
Ever since I started creating my own course content, I share it online and license it with a Creative Common attribution. I also created several course videos during the COVID pandemic. All of these are accessible online.

2013 – present **Tutored projects with real clients and end-users**
Whether it is for undergraduate students at Laval IUT or graduate students at ENSIM engineering school, I like to provide them with real projects. I sometime propose them to develop parts of prototypes for my research projects but I prefer putting them in contact with local teachers who have a real need for custom Serious Games. The students therefore have real clients that are counting on them and the possibility to test their applications with end-users. It usually takes several student projects to create a final usable application but I believe the coordination effort is worth it for all parties. The created games are freely available online (e.g. *Chimory, EcrisTonZoo, Aux couleurs de l'océan, Get Your BUT, 2048 Atom*).

2017 – present **Project-based training with the help of university staff**

The *Ludifik'action* professional training course is original in the sense that it provided custom advice and follow-up for each trainee. The participants, who are teachers, are expected to create their own Serious Game and test it, in their class, during the duration of the training session (over a semester). They are also expected to sign up as a team. They can sign up with another colleague teacher for example but I recommend them to team up with an educational designer of their institutions, support staff they are often unaware of. During the training session, they are also asked to work with the university's FabLab manger to create the game material or the university's digital resource center if the game is digital. This training method was gradually improved over the years and is now part of my research contributions.

Collective responsibilities

2019 – 2021	**Responsible for promoting the Professional Test and Quality graduate degree** Creation of communication material (posters, brochures, slideshows, videos), presentations of the program in high schools through the Greater West region of France and organization of an open day.
2018 – 2022	**Co-creation of the Ethical and Digital Law program** In collaboration with the Faculty of Law, we set up a new program for law undergraduates. The aim of this course is to prepare law students for the major changes caused by digital technology and AI, and to help them understand the ethical and legal risks involved.
2014 – 2021	**Organization of the student forum** I organized an annual forum during which students in the Computer Science and Multimedia department of Laval IUT (200 students) can meet representatives from approximately fifteen universities and engineering schools.
2016 – present	**Responsible of the Laval IUT tablet fleet** I am in charge of the fleet of 60 tablets that the IUT provides to students for their classes and projects. As such, I manage loans, software updates, but also the annual renewal of the tablets by writing funding requests to the region. I also make the extra non-trivial effort of donating the tablets we no longer use to local schools.
2016 – 2019	**Elected to Laval IUT's council** I participated in monthly meetings to discuss and make decisions regarding the four departments of the IUT school.
2017	**Organization committee of the ATIEF's TEL MOOC** I participated in the creation of the TEL MOOC by shooting videos and interviewing researchers to create the introduction and the final video of the MOOC. I also presented my research projects in three other videos. This MOOC is still used in half a dozen masters specialized in TEL in French-speaking countries.
2014 – 2016	**Head of communication committee of the new Claude Chappe Institute** This institute regroups several labs, schools and universities. I organized meetings to find a name, set up the website and managed a contest to create the logo.

Co-supervision of PhD students

2021 – present	**Sebastian SIMON** Title: "Augmented Reality interactions for mobile collaborative learning" Director: Sebastien GEORGE (50%) Funding: ANR JCJC SituLearn project
2019 – present	**Sofiane TOUEL** Title: "Mixed Reality interactions for teaching fractions" Director: Sebastien GEORGE (50%) Funding: personal funding, working full time
2017 – 2021	**Wilfried MORIE** Defended on July 1st at Institut National Polytechnique, Ivory Coast Title: "Indexing tools and methods for finding educational games" Director: M. GOORE Bi Tra, Institut National Polytechnique, Ivory Coast (10%) Funding: national scholarship Ivory Coast and Campus France Current position: Associate Professor at Université Nangui, Abidjan, Côte D'Ivoire
2014 – 2018	**Aous KAROUI** Defended on September 21st at LIUM Title: "JEM Inventor: an authoring tool for mobile learning games" Director: Sebastien GEORGE (50%) Funding: national grant Current position: CEO of Mindful House, a company he founded after his PhD

Supervision of Bachelor and Master Students

I have supervised the internships of 9 Master students (BS), 9 Bachelor students (BS) and one teacher doing a University Diploma (DU). The high proportion of BS is explained by the facts that it is hard to attract interns in Master's degree since Laval is a small city with no university. I hire students in computer science to produce functional TEL prototypes and students in multimedia and game design to improve the interface and interactions which are very important for projects related to Serious Games. They also work on guides and tutorials to help teachers understand the functionalities of the TEL tools and how they can use them to their full education potential. Finally, I also hire students in social sciences, who are co-supervised with colleagues from the CREN, to analyze the use and the impact of TEL in class. When it is possible, I offer my PhD students and post-doctorates the possibility to co-supervise interns with me.

2023	**Moise BERTHE** (MS, computer science, Université Lyon 2) Title: "A dashboard to visualize emotions during learning with Augmented Reality" Co-supervision: Mohamed EZ-ZAOUIA (post-doctorate) Funding: MIXAP
2023	**Mouhamed SOW** (BS, social sciences, Université de Tours) Title: "Usage analysis of Mixed Reality on schools" Co-supervision: Cendrine MERCIER (CREN) Funding: MIXAP
2023	**Alexandra FREITAS ALVE** (BS, multimedia, IUT de Laval) Title: "Promotion of research projects" Funding: SituLearn
2023	**Guillaume BOUCHER** (BS, multimédia, IUT de Laval) Title: "Design and development of a demonstrator for the SPART technology" Co-supervision: Sebastian SIMON (PhD student) and Alice DINSENMEYER (LAUM) Funding: collaboration grant to promote inter-laboratory collaboration
2022	**Marielle DROUIN** (BS, multimedia, IUT de Laval) Title: "Graphical design for promoting research projects" Funding: MIXAP
2022	**Moez ZAMMIT** (MS, social sciences, Université de Nantes) Title: "Analyzing individual and collective learning activities during field trips" Co-supervision: Christine VIDAL-GOMEL (CREN) Funding: SituLearn
2022	**Maysa OUESLATI** (MS, computer science, ESPRIT engineering school Tunisia) Title: "Augmented Reality for mobile serious games" Co-supervision: Mohamed EZ-ZAOUIA (post-doctorate) Funding: Mindful-House Company
2022	**Milushka CHAMOCHUMBI** (MS, social sciences, Université de Nantes) Title: "Analyzing the use of TurtleTablet in an ecological setting" Co-supervision: Christine VIDAL-GOMEL (CREN) Funding: TurtleTable(t)
2021	**Ulysse CHENUT** (BS, multimedia, IUT de Laval) Title: "Graphic design of the Magic Cauldron application and its game material" Co-supervision: Sofiane TOUEL (PhD student) Funding: SMART-Fractions
2020	**Clément BOUSSARD** (BS, computer science, IUT de Laval) Title: "A dashboard to visualize the usage tracks of TurtleTablet" Funding: TurtleTable(t)

2020	**Rozenn DAGORNE** (BS, multimedia, IUT de Laval) Title: "TurtleTablet: a collaborative educational game" Funding: TurtleTable(t)
2020	**Gaëlle CORGNET** (DU, neurosciences and Learning, Université d'Angers) Title: "Teaching emotions with Virtual Reality: analysis and improvements of TGRIS" Funding: TGRIS
2020	**Baptiste JAMET** (BS, computer science, IUT de Laval) Title: "TurtleTablet: recognizing tangible objects on a tablet" Funding: TurtleTable(t)
2019	**Quentin HERMANN** (MS, social sciences, Université de Nantes) Title: "Usage analysis of TurtleTablet in an ecological setting" Co-supervision: Géraldine BODY (CREN) Funding: TurtleTable(t)
2019	**Adrien DUPORGE** (MS, game design, Gamarora school) Title: "Game mechanics to promote collaboration" Co-supervision: Sébastien GEORGE (LIUM) Funding: TurtleTable(t)
2018	**Mamadou KEBE** (MS, computer science, Université de Sfax, Tunisia) Title: "Piloting interface for an interview with an embodied virtual agent" Funding: TGRIS
2017	**Evan MOTTAIS** (BS, computer science, IUT de Laval) Title: "Tangible objects on Interactive tabletops" Co-supervision: Sébastien GEORGE (LIUM) Funding: TurtleTable(t)
2014	**Emna JEMLI** (MS, ESAIP engineering school, Angers) Title: "Mediated collaboration with smartphones in crowds » Funding: none
2013	**Jonas CELANDER GUSS** (MS, computer science, KTH, Stockholm) Title: "A Participative Light and Sound Show using Mobile Phones in Crowds" Co-supervision: Gunar KARLSSON (SICS) Funding: CrowdFlash

In addition to these internships, I also supervise 2 to 5 groups of student projects per year, in my computer science department of the Laval IUT but also in the multimedia department of the Laval IUT and the ENSIM engineering school in Le Mans. I offer subjects in relation to my research projects such as developing exploratory functionalities of TEL prototypes or creating logos and visuals for the projects.

5 Impact on the Community

Science outreach

When I was child, I wanted to be an "inventor". I wasn't yet familiar with the term "researcher", but I can now say that it really is the job I've been dreaming of. It's a fascinating job that combines intellectual challenges with technical progress and, in my case, produces TEL tools and methods that can be immediately applied in schools. The pay is decent, but above all, it gives me the feeling of being useful to society, and I am convinced that many other young men and women could have the same vocation. I have therefore been communicating about my profession since the very beginning of my PhD, 15 years ago, by organizing and taking part in events in addition to publishing articles in the general press.

Type of communication	**Number**
General press	10
Book chapters	1
Radio interviews and podcasts	5
Animations	31
Videos	3
Portraits and exhibitions	3
Invited talks	6
Event organization	1
TOTAL	**60**

Specific actions to promote women in STEM

As a teacher, I can only observe the lack of girls in Computer Science (1 or 2 maximum per promotions of 60 students). And yet, the digital sector offers numerous employment opportunities. This situation can be changed, as in other countries, such as Tunisia and Lebanon where there are more women than men in the field. Over the past six years, I have therefore set up specific initiatives to encourage young girls to take up computer science. In addition to national campaigns, I am also an active member of the Women in Science 53 initiative organized by the local science museum. Specific actions to promote women in STEM are identified with the in the following lists.

General press

2023 "MIXAP: an augmented reality creation tool for teachers", RA'Pro blog

2022 "The contribution of public research", Edtech thematic publication, SATT Ouest Valorisation

2022	“SituLearn: for educational outings on Smartphone”, Ambition IUT Magazine
2021	“She creates educational applications for teachers”, Le Maine Libre
2021	"I want to be an astronaut" with five other ESA candidates, Le Parisien
2021	Portrait in Transistor magazine’s special issue on youth and culture
2021	“Students create an application to teach children colors”, Ouest France
2020	“TGRIS: Virtual Reality Simulator for Managing Emotions”, Laval Virtual Blog
2020	“GALA, international conference dedicated to Serious Games”, Laval Virtual Blog
2020	“TurtleTablet, a Mixed Reality game for learning programming”, Laval Virtual Blog

Book chapter

2022	Chapter « At the heart of the algorithme » in the book Algorithms, Predictive Justice and Robot Judges , S. Lebreton-Derrien et R. Raher, édition Enrick B., 104 p.

Radio interviews

2023	“LIUM’s Edtech Conference”, l’Autre Radio
2021	“The objectives of the MIXAP project”, Radio Alpa
2021	“Advantage of digital tools for learning during COVID”, Radio Alpa
2020	“GALA International Scientific Conference”, l’Autre Radio
2020	Presentation of my research and career, Indéscience podcast

Animations

2023	MIXAP stand at the Edtech Grand Ouest event, Rennes
2022	Workshop at the IFSEC teacher training day, Rennes
2022	Workshop at the Maison pour la Science professional teacher training day, Rennes
2021	Radio France live broadcast "In duplex from the ISS with Thomas PESQUET", Paris
2021	Participation in the Speed Searching session, European Researchers’ Night
2017, 18, 21, 23	Stand at the Laval Virtual international exhibition
2016 - present	Annual visits to local schools
2008 - present	Animations at the national science fair (*Fête de la science*) since the start of my PhD

Videos

2021	Participation in the video on women in science in the Greater West, Atlanstic2020
2011	Teaser video to promote the Doc'Up PhD student association festival, Paris
2010	Short film made for my PhD, Doc'Up PhD student association festival, Paris

Portraits and exhibitions

2019	Portrait in the "Wonen in digital science" exhibition, Atlanstic2020
2020	"Research under lockdown", Le Mans Université, European Researcher's Night
2010	Portrait in the These's art project, Lyon 1

Invited talks

2023	"MIXAP: an authoring tool for Augmented Reality educational applications", National day on Open Educational Resources (Libre éducatif), Rennes, 200 teachers
2022	"Digital technology as a creative tool", Digital'ON festival, Allonnes
2022	"Digital + Game + Education = Serious Games", NSI Day, organized by the French Association of Computer Science Teachers
2022	"Research projects: augmented reality by teachers", series of webinars on gender equality, Ministry of Education
2021	"Digital professions", Laval jobs week, 400 high school students
2021	Round table, digital careers day, Science center, Laval, 500 high school girls

Event organisation

2021	Co-organization of Aurélie JEAN's visit to Laval "Do algorithms make the law?", 500 students

Open Educational Resources

Free, and sometimes open-source, TEL tools

2023	**MIXAP**: an authoring tool for teachers to create Augmented Reality applications Freely accessible at https://mixap.univ-lemans.fr/ + teacher guide Open-source code on the national education FORGE at https://forge.aeif.fr/
2023	**SituLearn**: an authoring tool for teachers, museums and cultural centers to create smartphone applications for field trips and interactives visits Freely accessible at https://situlearn-editor.univ-lemans.fr/ + teacher guide Open-source code on the national education FORGE at https://forge.aeif.fr/
2022	**The Magic Cauldron** and **Quizz App**: two games that can be used, in autonomy to work on the notion of fractions Freely accessible at https://smart-fractions.univ-lemans.fr/
2021	**TurtleTable** (for interactive tabletops) and **TurtleTablet** (for tablets, smartphones and computers): a collaborative game to introduce the basics of computer programming Freely accessible at https://turtletablet.univ-lemans.fr/ + teacher guide
2020	**JEN-Planet**: a catalogue to help teachers find Learning Games Freely accessible at https://jen-planet.univ-lemans.fr/
2020	**WriteYourZoo** (*Ecris ton zoo*): a game to teach children how to read (student project) Freely accessible at https://lium.univ-lemans.fr/ecris-ton-zoo/
2020	**Ocean colors** (*Aux couleurs de l'océan*): a game to help children learn the names of colors (student project) Freely accessible at https://lium.univ-lemans.fr/aux-couleurs-de-locean/
2019	**GetYourBUT**: a game to present the Laval IUT Computer Science department at the open house, science fair and student forums (student project) Freely accessible at https://lium.univ-lemans.fr/get-your-but/
2018	**2048 Atomes**: a game to learn Mendeleev's periodic table (student project) Freely accessible at https://lium.univ-lemans.fr/atomes/
2018	**Chimory**: a game to help university students review chemical transformation and an editor so teachers can update or add transformations (student project) Freely accessible at https://la-chimory.univ-lemans.fr/

2017	**TimeLine generator**: an editor that allows teachers to create a timeline-like game with a list of events and dates. Freely accessible at https://lium.univ-lemans.fr/timeline-editor/

Course material and video tutorials

Material	Course material available at http://free.iza.free.fr/teaching.php
Videos	8 videos with course content and 17 videos on research projects (project presentation, demos and teacher tutorials) Available on https://www.youtube.com/@izamarfisi8864

Transfer to the private sector

2023	Transfer of SituLearn to the Ozytis company
2023	Transfer of Quizz App and The Magic Cauldron to the Plaisir-Math company
2018	Transfer Jem-inventor to the Mindfull House spinoff company created by Aous KAROUI after his PhD thesis.
2019	Professional training for the GESTAMP company for creating a custom Serious Game for their internal training program.
2019	Custom professional training on Serious Games from the University of Saint-Etienne.

6 Awards

2023	**Prize Foundation Grand Ouest**, in the category "encouragement", for the MIXAP project. Organized by the Banque Populaire de l'Ouest, Rennes, France
2023	**Best poster award** at the European ECTEL conference for the short paper "Towards an authoring tool to help teachers create mobile collaborative games for field tips" 1/21 poster rewarded, Toulouse, France
2023	**Trophy innovation campus Le Mans – Angers**, in the category "transition", for the Jem-Inventor project with Sébastien GEORGE. Organized by the SATT Ouest Valorisation, Le Mans, France
2022	**Best paper award** at the international Games and Learning Alliance conference (GALA), for the paper "10 Commandments of the Serious Game Padawan: Lessons Learned After 4 Years of Professional Training". 1/27 paper rewarded, Tampere, Finland
2022	**3rd prize at the International Serious Game competition** of the Games and Learning Alliance for The Magic Cauldron, in the category "research" 3/26 games rewarded, Tampere, Finland
2021	**Awarded Rising Star** of the Pays de la Loire region, France Program to encourage young researchers to submit an ERC European project
2021	**1st prize at the European Conference on Game Based Learning** (ECGBL), for TurtleTablet, in the category "games installed on devices" 4/32 games rewarded, Brighton, UK
2020	**1st prize at the photo contest** "Research under lockdown" Organized by Le Mans Université, European Researcher's Night, Le Mans, France
2018	**PEPS Prize** - Passion for Pedagogy in higher education, national competition for the Ludifik'action training program 6/125 projects rewarded, Paris, France
2013	**Selected for an ERCIM Marie Curie excellence postdoctoral scholarship** European Marie Curie co-fund fellowship, Stockholm, Sweden
2010	**Audience Award at the short film festival** made for my PhD Organized by the Doc'Up PhD student association, Paris, France

Part II

Research Works

CHAPTER 1

Introduction

Exploring the potential of serious games, mobile learning and innovative human-computer interactions for learning

Chapter 1

Introduction

Exploring the potential of Serious Games, Mobile Learning and Innovative Human-Computer Interactions for Learning

Contents

This manuscript gives an overview of the research we[1] have conducted in the field of **Technology Enhanced Learning** (TEL). The research has been mainly conducted in the computer science laboratory of Le Mans University (Laboratoire d'Informatique de l'Université du Mans, LIUM) in France. As will be explained throughout this manuscript, the research has been carried out in collaboration with teachers, PhD students and colleagues in the fields of Computer Science and Humanities and Social Sciences. As depicted in *Figure* 1.1, TEL is, by essence, a multi-disciplinary field of research. The TEL tree of knowledge is nourished by technological advances in **Computer Science** as well as learning and teaching theories that come from various disciplines of **Humanities and Social Sciences** (e.g., Didactics, Educational Sciences, Psychology). As we will see later, a more accurate representation would look like a graph because

[1] "We" is used in this manuscript when referring to research conducted by my colleagues and myself. "I" is used in the last chapter, as it deals with my own research perspectives even though they will most certainly be led in collaboration with other researchers.

the branches can merge, but let us use this simplified vision for the time being. Even though we will focus on our Computer Science contributions in this manuscript, all our projects involved Social Sciences researchers. This essential collaboration, at times difficult, will be discussed in *section* 4, which focuses on our research method. In *section* 1.1, we will briefly introduce the field of TEL and its main branches. In *section* 2, we will focus on the three branches to which we have contributed (Serious Games, Mobile Learning and novel Human-Computer Interactions for learning) and in *section* 3, we present our two main research objectives: creating effective and efficient educational tools and empowering teachers!

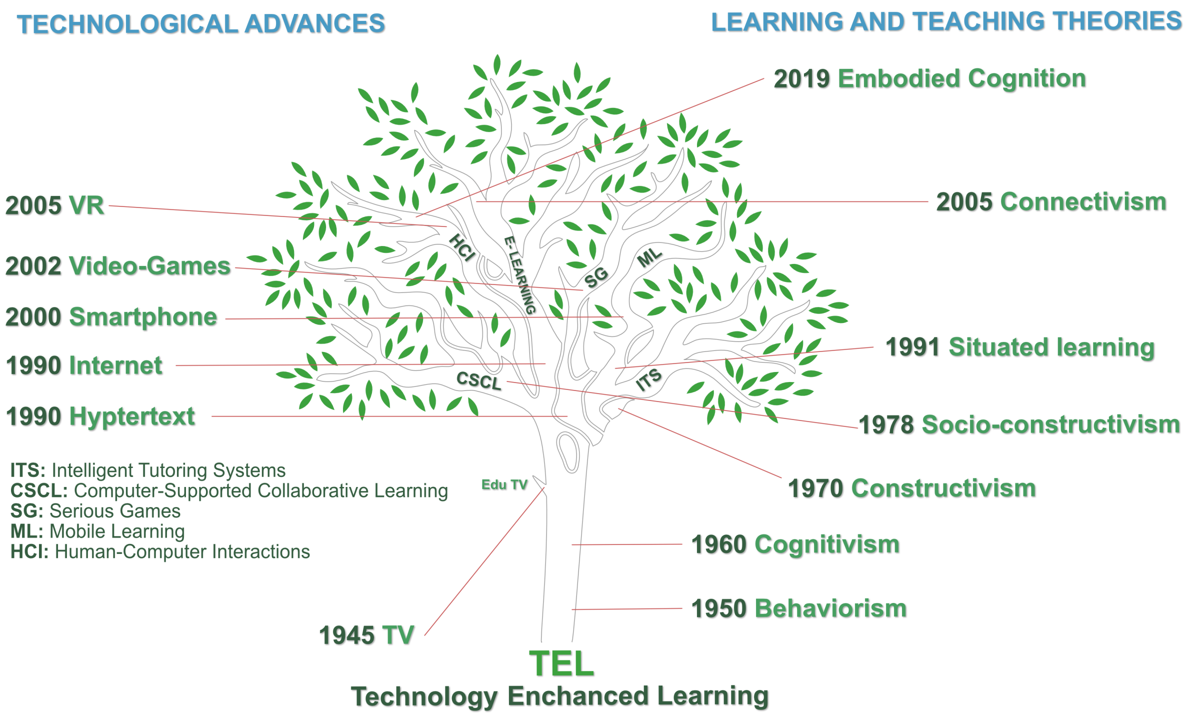


Figure 1.1: The many branches of Technology-Enhanced Learning

1 Research context: Technology-Enhanced Learning

TEL is a fairly new field of research. The dates in *Figure* 1.1 locate its major theories and technological advances on a timeline. And even though some date back to the 1950s, the field only flourished as of the 1990s with the invention of Hypertext, the Internet and the advent of personal computers in homes and schools. TEL is not merely a product of technological advances; it is nurtured by learning and teaching theories, that are often much older. Let us briefly present the main theories to better understand how they have shaped the field.

1.1 Teaching and Learning Theories

First, there are three major learning theories worth mentioning. In the early 1900s, **Behaviorism** became the predominant learning theory (Watson, 1913). It is based on the belief that knowledge is exterior to the learner and that learning is achieved by providing them with stimulus (negative or positive feedback) until they change their behavior. The famous experiment Pavlov led with a dog is a very good example of how this theory can be implemented. In the 1960s, a new theory, called **Cognitivism** (Piaget, 1967), appeared. Unlike behaviorism, it focuses on the idea that learners process information and, little by little, build their own mental models. Finally, the theory of **Constructivism** appeared in the 1970s. The main difference with cognitivism is the role of social context. While cognitive theory views learning as a purely internal and mental process, constructivism views learning as a combination of cognitive development and human interaction (in our case interaction with the teacher and with fellow learners) that contributes to constructing knowledge (Vygotsky, 1980). A sub-branch of Constructivism, called **Social-Constructivism**, even identifies the relationship with others as the most important factor of learning.

Koschmann introduces his book by explaining how these learning theories have modeled the field of research in TEL, from simple instructional tools, to intelligent tutoring system and finally to open words and simulations with tools to foster collaborative learning (Koschmann, 1996).

More recent teaching and learning theories have also contributed to shaping the field of TEL. Situated-Learning, for example, is an instructional approach that claims students are more inclined to learn by actively participating (Lave and Wenger, 1991). Field trips, where students actively take part in the learning activities set in natural environments, are a good example of this approach. The concept of **Situated-Learning** became the corner stone for research in Mobile Learning, an approach that offers new ways of learning on-site with mobile technology. Another recent theory, **Connectivism**, addresses learning in the digital age (Siemens, 2005). It emphasizes how internet technologies such as web browsers, wikis or networks created on forums and social media contribute to new ways of learning. Lately, theories dealing with **Embodied Cognition** have also been used to justify the benefits of using digital tools and tangible objects (Shapiro and Stolz, 2019).

Several key ideas of these learning theories are recurrent in all branches of TEL research. In particular, three key notions are identified by Lev Vygotsky, the father of Constructivism.

The notion of the **more knowledgeable other** is the foundation of Intelligent Tutoring Systems and all TEL systems that provide automatic help and feedback. A computers can provide a student with helpful and timely information. And, unlike a human, it is always available and does not get tired of endlessly repeating itself. TEL can also provide collaborative tools to put learners in contact with one another, thus freeing teachers and giving them more time to focus on students with specific tutoring needs.

The nature of the given information and the right moment to provide it can be generated by **scaffolding** models. This notion refers to the way teachers identify when a student needs help and the right amount and type of help that should be provided, while keeping in mind that the objective is to remove the scaffolding once the concept has been mastered. The learning that occurs with this scaffolding is referred to as the **Zone of Proximal Development** (ZPD), in other words, what the learner can do with guidance (*Figure* 1.2).

But TEL cannot be reduced to computer science and learning theories. When developing tools for TEL, fun and engagement are at the heart of the design, especially with Serious Games (i.e., games to learn). This entire branch of research uses the concept of **Flow**. Developed by the psychologist Csikszentmihalyi, it refers to a highly focused mental state conducive to productivity (Csikszentmihalyi, 1990). This concept is used to design learning activities, also called "game levels" in the field of Serious Games, and adapt them to the learners. The idea is to keep the learners in a productive flow channel, between boredom (generated by activities that are too easy) and anxiety (generated by activities that are too difficult). The notion of flow presents several similarities with that of Zone of Proximal Development and several researcher have even proposed merging them (Basawapatna et al., 2013) (*Figure* 1.2).

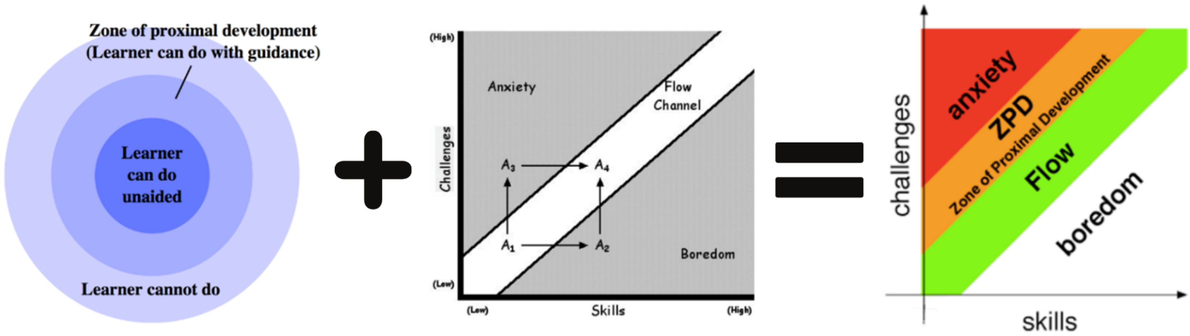


Figure 1.2: Merging the Zone of Proximal Development with the concept of Flow

Let us present one last learning model that is frequently used in TEL research, but is often misconstrued! Edgar Dale's **Cone of Experience** is usually cited to support the fact that TEL systems are more effective than traditional lectures (Dale, 1946) and is presented as in the left side of *Figure* 1.3. However, this cone includes elements that are not in the original publication (Subramony et al., 2014). The original cone, presented on the right side of *Figure* 1.3, does not have any suspiciously-round numbers or any mention of memory. It simply shows the progression of learning experiences from the abstract to concrete. For example, Verbal symbols (top of the cone) are considered abstract whereas Contrived experiences (2nd level from the bottom) refers to activities with mockup-models or simulators that provide experiences that are as close to reality and as concrete as possible. Having said this, the main idea behind the frequent misconstruction, illustrated by the cone on the left, is not totally wrong. Indeed, studies have shown that when more senses are involved in processing information, the brain is more solicited, thus forming a better neural network in the brain (Johnson and Mayer, 2009)(Clark and Paivio, 1991). The original cone also advocates the notion of active participation in realistic or real environments. These types of activities can be recreated in TEL, especially with new immersive technologies such as Virtual Reality (Tracey et al., 2010).

1.2 Evolution of TEL alongside technology

While research in TEL is nurtured by learning and teaching theories, it is also very much influenced by technological advances. If a new technology fosters new ways of learning, a new branch in TEL research generally appears. If this research yields favorable results, the branch flourishes and creates yet more branches that explore new TEL systems. But sometimes, the branch just dies out. For example, the invention of TV in 1927, and especially its massive appearance in households after 1945, gave birth to a research branch devoted to educational TV. Even if there are still a few project such as *Lumni*[2] or *L'université de tout les savoirs*[3], this branch mainly

[2]https://www.lumni.fr/, consulted on the 5th of September 2023
[3]https://www.canal-u.tv/, consulted on the 5th of September 2023

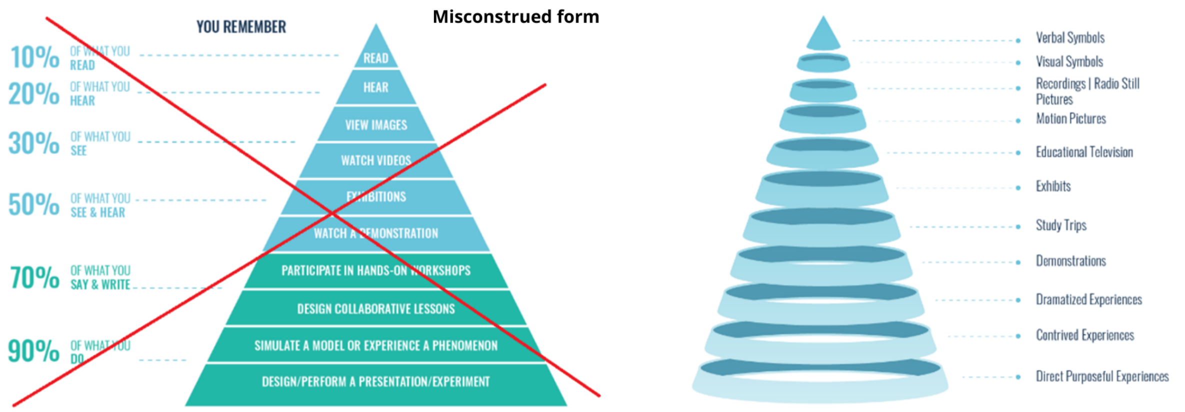


Figure 1.3: Edgar Dale's Cone of Experience in its misconstrued and correct form

died out only 10 years later. It is primarily the invention of hypermedia, in the 1980s, and the Internet, in the 1990s, that launched the TEL research community. As is depicted in *Figure* 1.1, dozens of research communities started working on broad topics such as computer-assisted learning or more precise topics such as e-learning. The research branch devoted to Intelligent Tutoring Systems (ITS) has its roots in the constructivist theory and continues to grow with the development of embodied conversational agents and numerous innovations in Artificial Intelligence. The branch related to Computer-Supported Collaborative Learning (CSCL) developed based on the social-constructivism theory. Try to imagine this as a magical tree where the branches intertwine and sometimes merge with one another.

In the next section, we will provide more information on the development of the three branches we have contributed to.

2 Three research branches

Our research relates to three research branches within TEL: **Serious Games** (SGs), **Mobile Learning** (ML) and innovative **Human-Computer Interactions** (HCI) for learning. For each of these branches, we will provide a definition, its history, explain when and why we started working in this branch and, finally, point out its major research challenges. We focus mainly on the challenges related to Computer Science that we have tried to tackle during our research projects and that will be presented in this manuscript.

2.1 Serious Games

2.1.1 Definition

Our first topic of study is **Serious Games for learning (SGs)**. Another, more precise, but not as popular name is Learning Games. As shown in *Figure* 1.4., SGs combine the properties of learning environments, games and simulations. The main idea is to use game mechanics (e.g., competition, collaboration, social recognition, collection, exploration) and the simulation possibilities of computer programs to create engaging and rich learning-by-doing environments.

The simulation part is not necessarily visible, like in a flight simulator, but the SG should contain some type of activity or behavioral model related to the targeted skills. SGs can be used in all educational fields, from kindergarten to vocational training (Saunders, 1996). Thanks to the game mechanics, learners become central actors in their training, in contrast to the passive position they occupy most of the time in traditional education (remember Edgar Dale's Cone of experience). Moreover, as a study by the National Research Council (National Research Council, 2000) shows, learners become emotionally engaged in SGs, which facilitates the imprinting of their actions and decisions in their memory. SGs can therefore be used to facilitate the learning of certain skills for which traditional teaching methods are not satisfactory (Federation of American Scientist, 2006). Many studies have shown that, when well designed, SGs increase engagement, motivation and learning (Mayo, 2007), (Dondlinger, 2007).

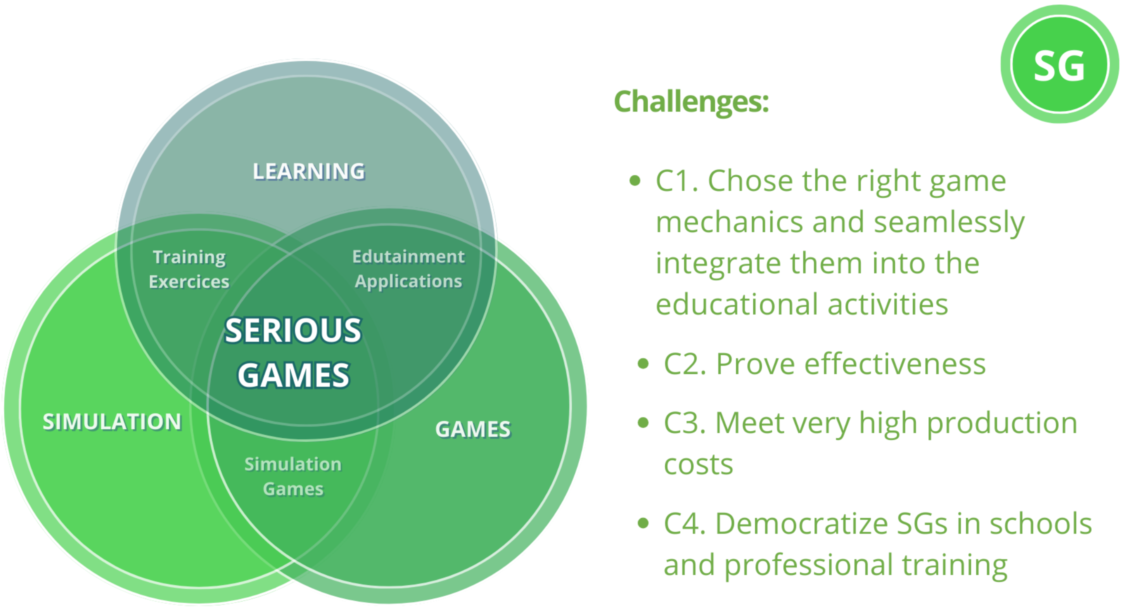


Figure 1.4: Serious Games for Learning

2.1.2 History

The SG research field developed in the 1990s and is based on the theory of flow (Csikszentmihalyi, 1990) and storytelling models. The field has also been strongly influenced by research in non-digital educational games (Thiagarajan and Thiagarajan, 2003). The SG field of research really only took off around 2005, with the massive development of videos games and research on game mechanics (Marczewski, 2015). The first famous SG was America's Army: a video game intended to promote the US military while attracting potential new recruits. In France, the first PhDs related to SGs where defended in 2007. I was part of this first generation, starting work on my PhD on methods and tools for designing Learning Games in 2008. SGs are still one of my main research topics and the research community has since grown very strong. Around 2015, a new sub-branch devoted to gamification appeared. It explores ways to make learning more engaging and fun by adding a layer of game mechanics on top of educational activities without changing them. It is important to say that SGs and Gamification are not necessarily digital and therefore englobe a large community of educators and teachers who develop these methods in their classes.

2.1.3 Challenges

The main research challenge in SGs is **the choice and integration of well-adapted game mechanics** (C1^{SG}) in order to reach the targeted educational objectives while providing a coherent gaming experience. Once the game mechanics are chosen, one needs to seamlessly integrate the educational activities into the game experience in order to promote intrinsic motivation (Szilas and Sutter Widmer, 2009), (Fabricatore, 2000). Simply sugar-coating the exercises with game mechanics, also referred to as "chocolate-covered broccoli", is not enough to create an engaging and effective learning experience. In fact, you can quite easily make a SG that is "worse" than a traditional class experience (Sawyer, 2002).

The second challenge is proving the **SGs' efficiency** (C2^{SG}). Even though games are a natural way for humans to learn, the use of game mechanics is still frowned upon in schools, even in primary schools. It is therefore paramount to explain why the game mechanics are being used and to reassure teachers, colleagues, directors, parents and even students that they are not "wasting their precious time at play".

The third challenge in the field of SGs is the **very high production cost** (C3^{SG}) for a very minimal return on investment (George, 2010). Producing SGs requires the same team of game-designers, developers and graphic artists necessary to develop a commercial video game ($32.8 million for America's Army), including at least one education expert (i.e., teacher). However, the difference with video games is that most SGs focus on a specific learning content, such as nosocomial diseases (Ney and Balacheff, 2008), which drastically reduces the target audience. And even for SGs that deal with very broad subjects such as fractions (Liu et al., 2013), the potential buyers are schools, which often have a limited budget.

Finally, the last challenge is to **democratize the use of SGs by teachers and professional trainers** (C4^{SG}). This is still very complex, due to the aforementioned design complexity and production cost. Another difficulty for mass adoption in schools is the fact that teachers need to adopt the SGs and feel at ease with them. Preferences for game mechanics is a very personal matter and a SG designed for one teacher will almost certainly not suit another.

After ten years of research, the research community has concluded that SGs have a positive effect on learning if they are designed and used correctly. The goal now is to provide guidelines and SG models that can, not only help create replicable positive results, but also lower production costs. To achieve this goal, research is now focused on developing technical toolkits, frameworks and Artificial Intelligence with interactive non-player characters and intelligent tutors.

2.2 Mobile Learning

2.2.1 Definition

Our second field of research is **Mobile Learning** (ML), also referred to as m-learning. This term covers any type of TEL tool that can be used on smartphones or tablets (*Figure* 1.5). Nowadays, with the improvement in network coverage, this term refers not only to smartphone applications but also web applications that are accessible on mobile devices. The potential to obtain information anytime and anywhere introduces a shift in the philosophical developments of learning (Herrington and Herrington, 2007). ML is a very broad field and we only focus on a subcategory: namely ML systems that harness mobility-related functionalities or other functionalities that use smartphone sensors such as accelerometers, gyroscopes, cameras, audio recorder, calls and instant messaging. These functionalities offer many advantages for learning. Geo-location, for example, is especially useful to provide just-in-time information and situated activities, when the learner is physically in front of the object of interest (i.e., castle, tree). It also encourages students to physically move in order to discover information which is a good game mechanic and helps them to remember information (Hubbard, 2007), (Schwabe and Göth, 2005). The smartphone's camera can also be used to project augmentation on an archeological site or a building for educational purposes (Pombo et al., 2018), (Loiseau et al., 2013). Finally, the smartphone's calling and instant messaging functionalities are very useful to promote collaborative learning (Huizenga et al., 2007).

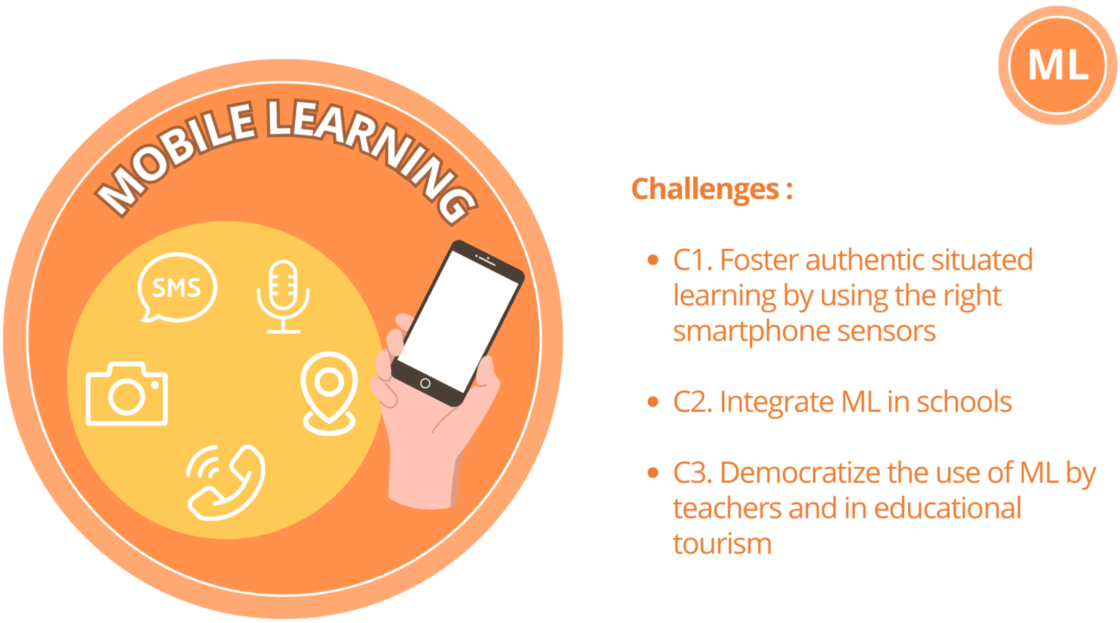


Figure 1.5: Mobile Learning

2.2.2 History

Research related to ML has its origin in the Situated Learning theory. Even though their are earlier projects with PDAs, it really developed in the early 2000s along with mobile technology (tablets and smartphones). I became involved in this community in 2012, during my postdoctorate at the Mobile Lab of the Swedish Institute of Computer Science. I worked on an interactive light show for crowds that uses an opportunistic network to connect smartphones directly with one another. At a concert or sporting event, the crowd would create a dynamic and fluctuating light show with their connected cell phone screens. Since then, the software and hardware in smartphones have evolved at incredible speed, providing many new functionalities for situated learning such as 3D cameras, precise GPS location, movement sensors and NFT readers.

2.2.3 Challenges

The main challenge we have pursued in ML is to find ways to **foster authentic situated-learning** (C1[ML]) by making a judicious choice of smartphone functionalities and educational activities. It does not suffice to simply show geo-located information or ask learners to answer questions when they arrive at a point of interest. The educational content needs to be redesigned to take into account the fact that students are on the move (in potentially dangerous environments such as city streets) and cannot therefore be required to take notes or read long texts on small screens. Activities also need to be designed in such a way that learners need to be on site and observe their surroundings in order to complete them (Klopfer and Squire, 2008).

The second challenge is to **integrate the use of Mobile Learning in schools** (C2[ML]). Currently, most ML tools are provided by museums and cities. Very few are used by teachers even though they could be very useful for their educational field trips. At the very least, teachers in natural sciences, history and sports could benefit from using ML on a regular basis. However, the adoption of such tools in schools is far from simple, for several reasons. First of all, smartphones are strictly prohibited, by law, in middle and high-schools (JOFR, 2018). Even though an exception can be made for educational purposed, teachers and school principals usually prefer to strictly enforce the law. Using personal devices can create inequities among students, and teachers will therefore only consider using school tablets, if they are available. However, these tablets often have restrictions that block downloading new apps and no SIM card for mobile data connection, which pretty much eliminates all geo-located applications that could be of interest for teachers' local field trips. Several groups of researchers have therefore started working on authoring tools that would allow teachers to create their own educational geo-located applications that could work on school tablets, but there is still much to be done.

Democratizing the use of ML in schools (C3[ML]),**but also museums and cities** is the last challenge of this field. Current applications are custom made for one museum or city and cannot easily be shared because the content is location-dependent. Several private companies offer their services for the creation of such applications but only very large museums and cities can afford such services. Authoring tools should offer a solution to this problem since they do not require developers and the content can be created by teachers or the museum and city staff themselves.

2.3 Innovative Human-Computer Interactions for learning

2.3.1 Definition

Finally, we are also involved in the field of innovative Human-Computer Interactions (HCI) for learning. This field is very wide and we will only focus on a very limited portion of technologies, namely Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) including tangible object for learning. These technologies offer many advantages for learning. Virtual Reality provides very realistic simulations of situation that are sometimes impossible, very expensive, or dangerous to create in reality (Huguet et al., 2016). This technology typically requires Virtual Reality headsets and is well adapted to medical training or technical maintenance in dangerous environments. Augmented Reality has the capacity of showing feedback directly on real objects, in their natural environment (Da costa et al., 2019). This technology is used, for example, with special AR glasses to help mechanics repair a car while they are manipulating the car parts. It is also what you use on your smartphone when you add rabbit ears to your face on Snapshat or when you play Pokemon GO. Several educational applications also use projectors to project augmentations directly on manipulated objects (Palaigeorgiou et al., 2019), (Beşevli et al., 2019). Mixed Reality can be situated on a continuum between Virtual Reality and Augmented Reality (Milgram and Colquhoun, 1999), (Kruijff et al., 2010). It blurs the boundaries by connecting real object manipulation with virtual elements. This combines the advantages of digital applications for learning with the advantages of manipulating real objects, which is paramount for acquiring certain concepts, especially when the learner is a child (Wilson, 2002), (Chandler and Tricot, 2015). Mixed Reality can be implemented on a variety of devices such as AR glasses, smartphones and tablets but also with sensors or conductive paint that are added to real tangible objects.

The term "eXtended Reality" (XR), covers Augmented Reality, Virtual Reality, Mixed Reality and everything in between (*Figure* 1.6). This term has become necessary, even among experts, as the boundaries between all these technologies has become less clear with the arrival of Virtual Reality headsets that also support Augmented Reality (Meta Quest Pro in 2022) and enable users to interact with virtual objects with simple hand gestures instead of using controllers (Apple Vision Pro in 2023).

To make this manuscript easier to read, these technologies will be referred to as (HCI) even thought we agree this acronym covers a larger variety of tools.

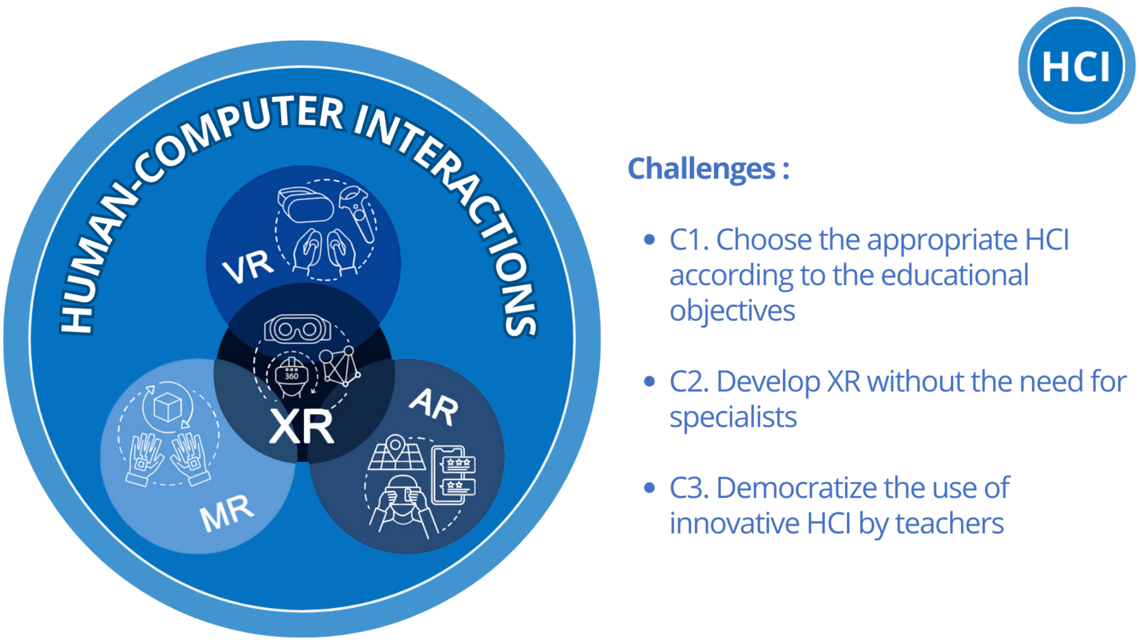


Figure 1.6: Human-Computer Interactions for learning

2.3.2 History

The research branch related to HCI is much older than the two other ones since it started in the 1960s. The theory of Embodied Cognition, published in 2019, gave a new impetus to this field, by providing a theory to explain why the use of tangible objects was so effective for learning (Radu and Antle, 2017). We joined this branch of research when Virtual Reality headsets started to become affordable in 2014. A few years later, in 2017, we also carried out a project on interactive tabletops with tangible objects. We quickly realized that, even though Virtual Reality headsets and interactive tabletops offer great potential for learning, these devices are currently not suitable for the majority of schools. The main reasons are the very limited suitable educational content available on these devices (Araiza-Alba et al., 2022) and the high cost (more than 2000 euros for an interactive tabletop). From then on, we therefore concentrated on HCI technology that could be used with the school's tablets, with the students' smartphones or that could be produced with Do-It-Yourself (DIY) methods or with 3D printers that are now mainstream in French schools. We have created several Augmented Reality and Mixed Reality applications and they are currently used in a dozen schools. In several recent projects, we also created authoring tools that enable teachers to create their own educational content.

2.3.3 Challenges

The main challenge in the field of HCI for learning is to **improve the quality of learning by using the appropriate interactions** (C1[CHI]). HCI can also be used as a way to enhance another approach such collaborative learning (CSCL). Because HCI implies additional organizational and technical constraints for teachers, its use must be counterbalanced with educational benefits.

The second challenge is more technical: **developing HCI is still quite complex and requires developers that are specialized in these technologies** (C2[CHI]). Researchers have therefore been working on technical frameworks to help basic developers use these technologies (Loup et al., 2018). Several researcher have even gone further by creating "no-code" applications that allow the creation of innovative HCI content without programming (Dengel et al., 2022). The principle is the same as authoring tools, but they often remain too complex and not necessarily well-adapted to teacher's needs (Ez-Zaouia et al., 2022).

The last challenge is to **democratize the use of innovative HCI in schools** (C3[CHI]). Like SGs and ML applications, HCI tools are custom designed for one teacher and their current class. Several private companies (e.g., Foxar, Eastern Peak) and research projects offer Augmented Reality applications that cover entire curriculums but the content is rarely suited to other teachers who have not participated in their design. Schools and universities will sometime advertise the fact that they use innovative VR or AR applications for the anatomy classes, for example, but their effective use remains anecdotal (Ley et al., 2022). The main reason is the fact that the content cannot be changed by teachers. How can we expect teachers to use applications that they cannot change, customize or even slightly adapt to their specific pedagogical objectives and needs?

This last question actually calls for a more profound reflection on how we perceive teachers: do we see them as parrots who merely repeat course content provided by others or do we see them as craftsmen and women who create customized content and activities? This is actually a wider question that is related to all branches of TEL research so I will keep it for the next subsections related to our research objectives.

3 Research objectives and projects

3.1 Research objectives

As you may have notices, some of the challenges in the fields of SGs, ML and HCI are similar. In particular, **all of their design processes are challenging**: whether it is choosing the right game mechanics for SGs and seamlessly integrating them into the educational content ($C2^{SG}$), choosing the correct smartphone sensors to foster situated learning ($C1^{ML}$) or choosing the right HCI according to the learning objectives ($C1^{CHI}$).

In the case of SGs, the design process is particularly complicated because it also needs to be backed up with arguments and proof of the game mechanics' effectiveness for learning ($C4^{SG}$). This design complexity is, of course, partly related to the fact that we are conducting exploratory research in relatively new fields or with new technologies. If it was simple, it would not be research! However, the designing of these TEL systems includes an additional layer of complexity because of their multidisciplinary nature. They involve a combination of models and theories from computer science and social sciences (games, didactics, education...) but also integrate hardware and software, without forgetting the real life constraints of teachers and schools. They therefore need to be designed by researchers in computer science and in social sciences but also with the collaboration of teachers and specialists in game mechanics (game designers), mobile technology and innovative HCI (specialized developers). **Our first research objective is therefore to provide methods, models and tools to help all these actors design effective TEL**. This objective is pursued by carrying out exploratory projects lead with a small number of pilot teachers. After a state of the art on similar TEL systems and co-design sessions with all the stakeholders, we formulate hypotheses and develop prototypes to test them in the classroom. This type of project provides insight into the most effective ways of using game mechanics, mobile sensors or HCI to foster learning.

The second challenge, that is recurrent in TEL systems, is related to their expensive production and their adoption by teachers and schools. For SGs, the main challenge is the high production cost ($C2^{SG}$). For HCI, it is the fact that the development must be carried out by highly qualified developers who are not available because they usually work in private companies for an impressive salary ($C2^{CHI}$). For ML, the difficulty is to get schools to accept the use of mobile devices ($C2^{ML}$) and, for all of these TEL systems, the last challenge is to democratize their use among teachers and other potential users ($C4^{SG}$, $C3^{ML}$ and $C3^{CHI}$). All these challenges can be addressed with a single solution: **authoring tools**. Authoring tools are built on models that come from exploratory projects such as those cited above. They enable teachers to create TEL systems, on their own, by integrating all these models and the technical knowledge of developers. They also allow teachers to be placed in the central role of content creators, making it easy for them to modify and update the content so as to adapt it to their needs or theirs students' profiles. The fact that the TEL systems are created by local teachers is also the best way to encourage schools to use them since they become part of the educational resources, just like exercise sheets. These types of projects can only be carried out on more mature research and are usually led with a larger number of pilot teachers to ensure the tool is well adapted to a large variety of profiles and needs. **Our second research objective is therefore to provide adaptable models and authoring tools to facilitate the development of TEL systems, and thus increase their acceptability and use by teachers**. In this manuscript the term "acceptability" is used to refer to the degree of acceptance demonstrated by the users. It is measured with standardized questionnaires, video analysis and self-confrontation interviews with users.

Figure 1.7 illustrates which challenges related to SGs, ML and HCI are addressed by this first and second research objective.

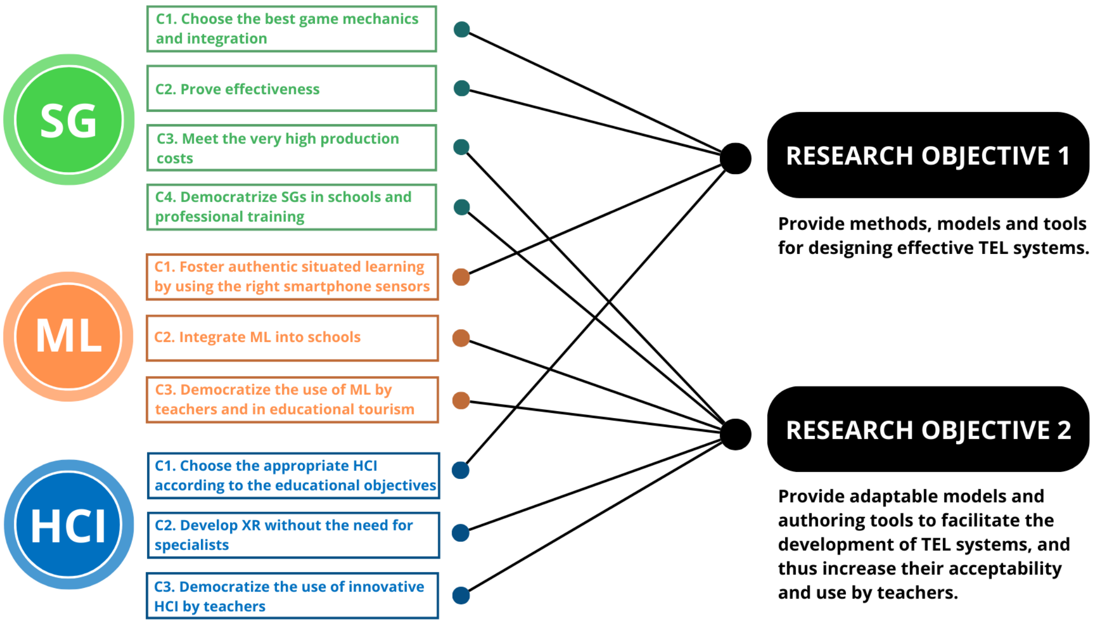


Figure 1.7: Challenges and research objectives

3.2 Research projects

Figure 1.8 illustrates a selection of projects I have taken part in or led during my career as leaves of the three research branches presented above. Some of these projects are more exploratory, and aim to achieve the first research objective (RO 1) by providing methods, models and tools to help design effective TEL systems. Others projects are more mature and aim to achieve the second objective (RO 2) by creating authoring tools for specific types of TEL systems.

As you can see from the project distribution in *Figure* 1.7, **my main field of research is Serious Games for learning (SGs)** but I have diversified and combined it with other fields of TEL. During my PhD, I was already working on methods, models and tools for designing SGs (RO 1). With my second PhD Student, Wielfrid MORIE, we worked on another tool: JEN-Planet (RO 1), an automatically-updating catalogue that helps teachers find existing SGs that could satisfy their pedagogical objectives and constraints. For the last six years, I have also set up and animated the Ludifik'action professional training course with several colleagues. It consists in accompanying teaches, for a period of five months, in the creation of custom SGs (digital or non-digital). Year after year, we have managed to perfect a custom SG design method (RO 1).

I started working in **Mobile Learning (ML)** during my post-doctorate. This is a field we continued to explore at LIUM, with my first PhD student, Aous KAROUI, who worked on the Jem-Inventor project. The objective was to enable teachers to create educational mobile applications for their field trips. Aous developed a generic model for educational field trips and

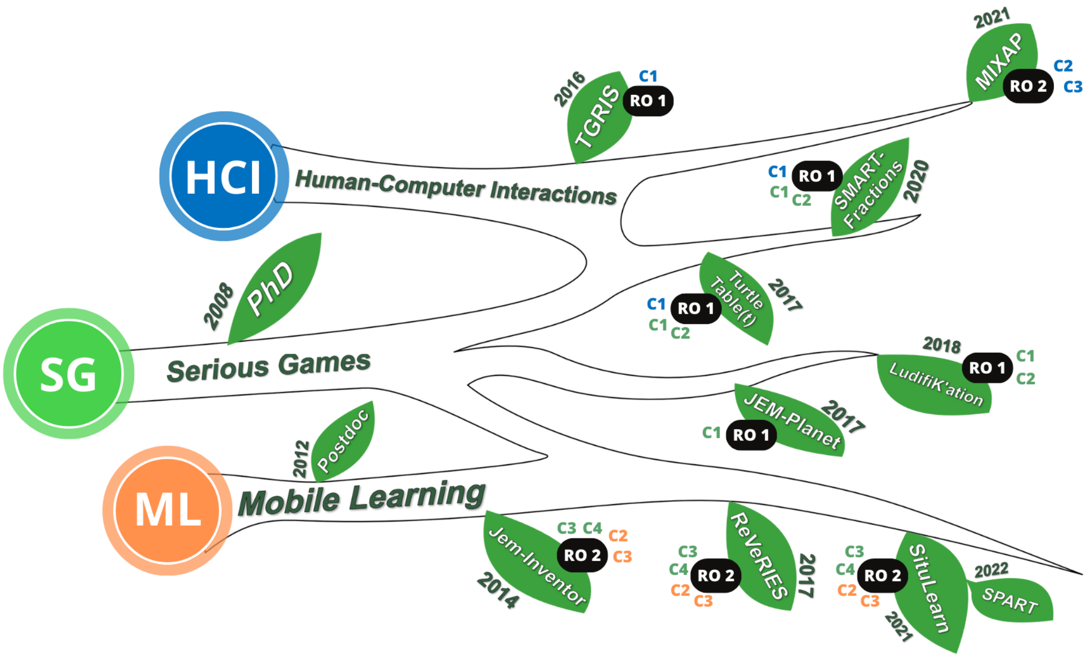


Figure 1.8: Contributions to three research branches of Technology-Enhanced Learning

an authoring tool (RO 2). With the help of other colleagues, we perfected this model during the ReVeRIES project (RO 2) with game mechanics and additional types of outings adapted to botany. Later, this model was further improved, during the current SituLearn project (RO 2), which is also aimed at museums and cultural centers.

Furthermore, we have several projects related to the branch of **innovative HCI for education**. TGRIS explores the potential of a Virtual Reality headset for dealing with emotions in professional settings (RO 1). Along the same line, we are currently designing the MIXAP authoring tool (RO 2) to help teachers create their own Mixed Reality educational applications.

At the **intersection between SG and HCI**, we have also made several contributions. The effectiveness of tangible objects to encourage collaboration was measured in the TurtleTable(t) project (RO 1). We designed, developed and tested several versions of the same SG aimed at teaching the basics of computer programming on various devices (interactive tabletops, computers and tablets), with and without tangible objects. Finally, the SMART-Fractions project explores the use of a Mixed Reality SG designed to learn fractions (RO 1).

Now that we have presented our research objectives and projects, let us describe the way these projects were conducted.

4 Research method

In this subsection, we will present three fundamentals that have defined our research method for all the previously mentioned projects:

- The first is essential yet difficult to master: working with colleagues in Social Sciences.

- The second is all too rare yet so enlightening: working with teachers and their students.
- The third will give you wings but will also help you keep your feet on the ground: working while having fun!

4.1 Working with colleagues in Social Sciences

As you are bound to fave understood by now, research in TEL is, by nature, multidisciplinary. It is at the crossroads between Computer Science and Social Sciences including didactics, educational science and psychology. I have systematically collaborated with colleagues in these domains for all the projects I have led.

Table 1.1 shows the colleagues with whom I have felt real collaboration that benefits the two parties and not just cooperation on the same research object. Collaborating does not always work out the way it is intended and some partnerships are much harder to implement than others. However, the time invested is well worth it, for the higher quality and complementarity of the research generated.

Table 1.1: List of colleagues in Social Sciences implicated in the research projects I have led

Project I have led	**Colleagues in Social Sciences**	**Precise field of expertise**
TurtleTable(t)	Géraldine BODY	Psychology and ergonomics
TGRIS	Isabelle VINATIER	Professional training didactics
SMART-Fractions	Nicolas PELAY	Math didactics
SituLearn	Christine VIDAL-GOMEL	Educational Science
	Aurélie LAINE	Psychology and ergonomics
	Robin HERON	Psychology and ergonomics
MIXAP	Cendrine MERCIER	Educational Science

Without claiming to be experts in multi-disciplinary collaboration, one of these colleagues and I wrote a paper on our experience for a workshop on TEL research epistemology (Marfisi-Schottman and Vinatier, 2020). This workshop lead to several contributions such as an overview of the answers provided by Computer Science and Social Sciences researchers related to research methods, tools and objectives (Mandran, 2023). The objective of our contribution was to provide a guideline to help young (and not so young) researchers in TEL set up collaborative projects. Our feedback is summarized as seven points of interactions or tensions that may exist between researchers in these two fields (*Figure* 1.9). Let us briefly present each of these points.

Research objectives: Each researcher has more or less long-term objectives throughout their research career, such as our two research objectives presented above. In order to have consistency in their research, researchers will favor certain types of projects and only partially invest in others. In order for a collaborative project to be successful, it must be in line with the personal objectives of each researcher involved. For example, in our TGRIS project, Isabelle VINATIER's objective was to make educational counselors more autonomous in their professional

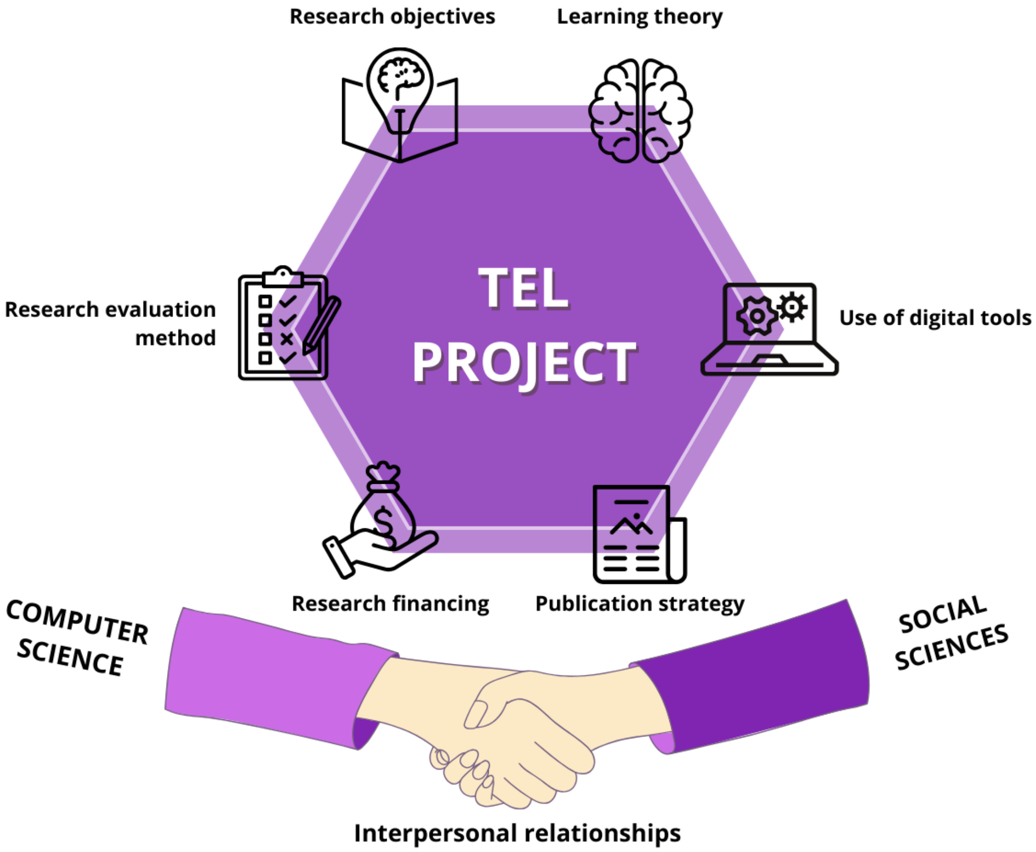


Figure 1.9: Interactions and tensions in collaborative multidisciplinary TEL projects

training and my objective was to create authoring tools to enable teachers to create their own educational tools. Our goals were perfectly in line with one another.

 **Learning theory**: It is also important that researchers agree on a common learning theory such as those presented in the first part of this chapter. For example, in the SituLearn project, our objective was to create digital tools to encourage collaborative situated learning during school field trips. For this project, we agreed with our colleges in psychology to work with the socio-constructivist and the situated learning theories.

 **Use of digital tools**: Researchers should also agree on the way the digital environment is going to be used and the identity of the primary end-user. This has an impact on the contributions of each partner. One possible stance is that the digital tool detains all the knowledge and is intended to be used by learners autonomously (e.g., TurtleTable(t) and SMART-Fraction). For these projects, computer scientists and social scientists design the TEL environment together and analyze the way the tools are used, or misused, by the students to improve them. The second

stance involves authoring tools that enable teachers to create their own digital tools and personalize the content (e.g., SituLearn and MIXAP). In this situation, teachers are the final users. For these projects computer scientists design the models and authoring tools adapted to the needs of teachers and researches in social science focus firstly on the appropriation of these tools by teachers, and then on their impact on students.

Research evaluation method: Evaluation methods are open to discussion. Indeed, there are many ways to evaluate the relevance of research, but they are more or less recognized in each discipline. Following a pragmatic constructivist research method, we combined multiple evaluation methods to obtain experimental data. For instance with the TGRIS project, we conducted a comparative study with a test group. We developed a pre-test and post-test to evaluate learning outcome in addition to using interviews, questionnaires and fine-grain video analysis. When it is possible, we also conduct medium-term experiments in which the tools are left with the teachers for a couple of months (e.g., SMART-Fractions).

Publication strategy: It goes without saying that the success of a project is measured, in part, by the number of publications it produces. In a multidisciplinary team, this can quickly become a point of friction, as there are very few conferences and journals that are recognized in more than one research domain (CNU sections in France). The practice we have is to each publish in our own field whilst including our fellow researchers as co-authors. This positive strategy has allowed us to multiply the number of accepted papers.

Research financing: The future of multidisciplinary projects such as ours depends entirely on funding. Because funds are notoriously difficult to obtain in Social Sciences, all of our projects were funded exclusively by the computer science team. Inter-laboratory contracts were set up in order to transfer part of the money to our fellow researches in Social Sciences and thus even out the funding balance.

Interpersonal relationships: Finally, for a collaboration to work well, people must respect and trust each other. These strong interpersonal relationships are essential in creating a positive working environment where skills are recognized and solutions are found when tensions arise. It is necessary to go beyond mutual understanding in order to build something together. Each researcher must "make room and leave space" for the other (others). This is only possible if each researcher knows how to silence his ego ;)

4.2 Working with teachers and their students

We create TEL systems in order to serve teachers and, in no way, to replace them. We co-design and test all our TEL systems with teachers as well as their students. Our research fully embraces the School-University partnerships philosophy (also called SUP), that aims at improving the quality of teacher education and research by sharing knowledge and experiences (Burton and Greher, 2007). Like Egenfeldt-Nielsen (2004) and Marne (2014), we believe that in order for a TEL system to be fully effective and adopted by teachers, the latter must have a central place in their design, whether it be from the very beginning of the process (RO 1), or by providing them with authoring tools so that they can create their own digital applications autonomously or modify them if they already exist (RO 2). As shown in *Table* 1.2, all the projects I have led involve pilot teachers. The exploratory projects (RO 1) involve a small number of pilot teachers (3 to 6) and the projects on authoring tools (RO 2) much more (17 in total for SituLearn and 19 for MIXAP). The *Ludifik'action* project involves 104 teachers and education designers since it takes the form of a training course carried out over several years.

Table 1.2: Number of pilot teachers involved in the projects I have led

Project I have led	**Number of pilot teachers involved**
TurtleTable(t)	3
TGRIS	6
SMART-Fractions	4
Jen-planet	6
SituLearn	21 - 7 for Jem-INVENTOR, 4 for REVERieS and 10 for SituLearn
MIXAP	19
Ludifik'action	104 teachers and educational designers

The method used to work with these pilot teachers is inspired by the Design-Based Research (DBR) method (Carroll, 1996). This method was developed to address several central issues of TEL such as the need to find solutions with the end-users (teachers and students) and the need to study learning phenomena in the real world rather than in a laboratory (Collins et al., 2004). Although DBR is a powerful paradigm for addressing these needs, it also presents us with two major challenges. First of all, it implies co-designing the tools with the end-users in an iterative way. Researchers therefore need to develop not one, but several prototypes, in close collaboration with the end-users. It is therefore essential to identify a group of pilot teachers willing to participate in the design and the pre-testing of all the tools. This is not so easy given the fact that there is no simple official way of paying pilot teachers with funding from research projects. DBR also emphasizes the fact that the tools should be tested in real-world learning environments. The developed tools therefore need to be robust and functional on all types of mobile devices. In addition, these tools need to last long after the research project if we want to benefit from the teachers' full collaboration. Our experience with several projects have proved how important it is to have robust tools for the experiments (Gicquel et al., 2019). After a few years of working with teachers, we therefore developed variations of the DBR method and strategies to be more efficient. These will be presented in the following chapter of this manuscript.

4.3 Have fun

We are so lucky to have a job in which we are given total liberty of thought and action. In any case, this is the way I feel in my research team at LIUM and I am very grateful for this.

I have found that having fun at work is an excellent way to motivate myself and get outstanding results. And even when the results are not as good as expected, the process was enjoyable and failure can easily be put into perspective. I was first initiated to this philosophy during my post-doctorate at the Swedish Institute of Computer Science. They would organize weekly fun group activities related to research (pre-experimenting tools) or not (ping-pong tournament, yoga, ice-skating and eating ice-cream).

As a researcher on SGs, I also feel we should use SGs for our everyday work when it is possible, not only because we have proof of their effectiveness, but also to remain credible! This is why I use gamification and game mechanics for some of my classes (UML and professional training) and I try to use them as often as possible in my research projects. I have applied the same principle to this accreditation diploma to supervise research (HDR) you are currently reading so you might find some of the passages or its format a bit unusual. I felt the need to transform this exercise into something more personal and fun. I hope it will also make it more enjoyable to read ;)

4.4 Content of the manuscript

This manuscript is composed of four chapters. You have just read the first introductory chapter that presents the research content and objectives. The next two chapters present a synthesis of our main contributions and limitations. *Chapter* 2 focuses on the first research objective (RO 1) and presents the methods, models and tools we have created to help design effective TEL. *Chapter* 3 focuses on the second research objective (RO 2) and presents the adaptable models and authoring tools we created for specific types of TEL systems. The last chapter takes a detailed look at my future research plans.

If you want to discover several TEL systems to learn fractions, the basics of computer programming or how to control your emotions, go to page 61, (*Chapter* 2).

I you want to skip the early projects and understand how we designed several authoring tools for teachers, go to page 99, (*Chapter* 3).

If you are the curious type and just want to know about the future, go to page 137, (*Chapter* 4).

If you are feeling lazy, you can always just scroll through this manuscript until you find the "Take away message" page at the end of each chapter.

TAKE AWAY MESSAGE

Our research is in the field of **Technology-Enhanced Learning (TEL)**. This field is, by nature, multi-disciplinary as it is built on learning and teaching theories (from Social Sciences) but also technical innovations (from the Computer Science).

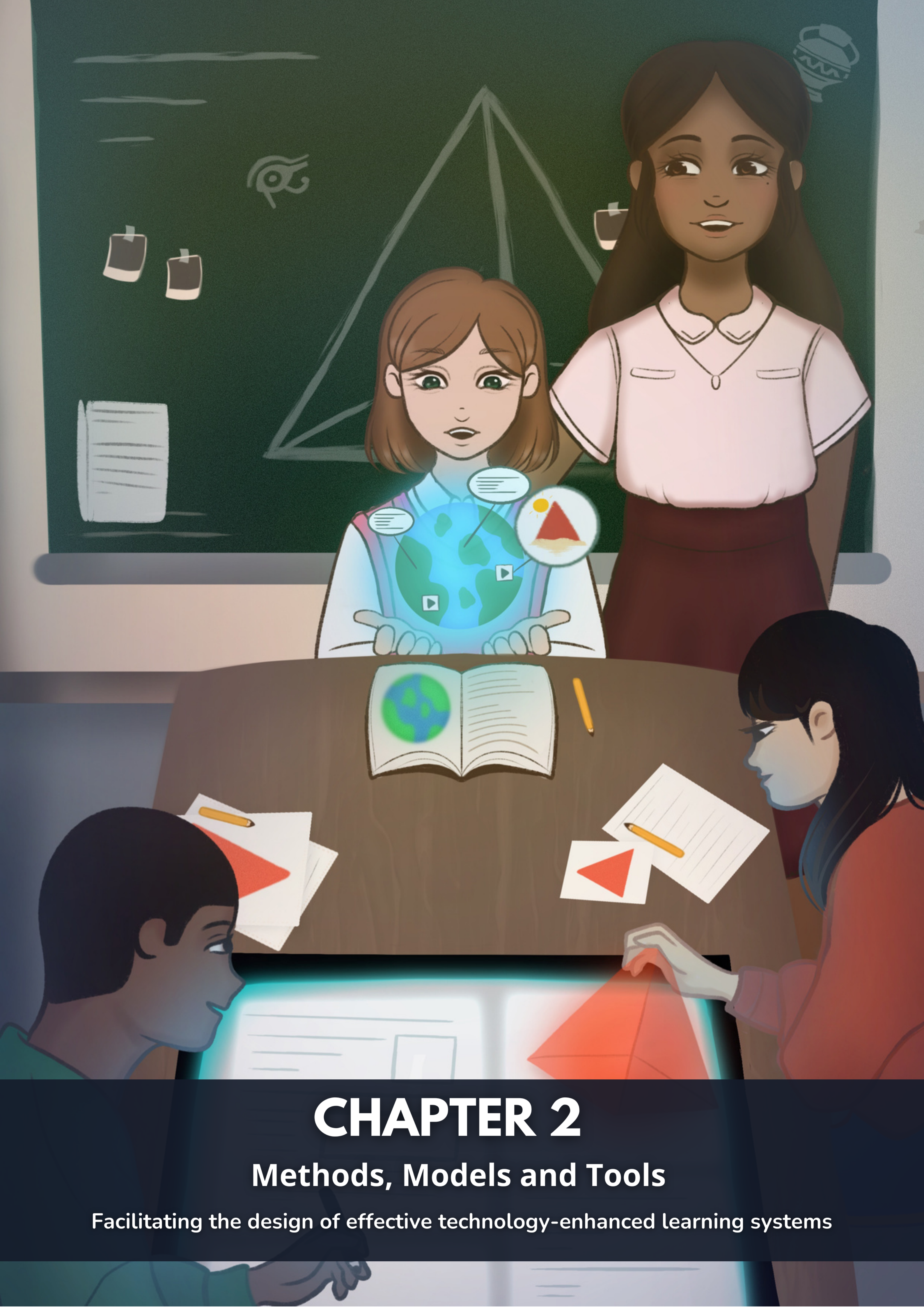
Our research contributes to three branches of Technology-Enhanced Learning:

- **Serious Games**
- **Mobile Learning**
- **innovative Human-Computer Interactions for learning**

These branches raise several common research challenges such as complex and multi-disciplinary design that involves actors who are not always available, high production costs and the need to democratize their use in schools. We therefore focus on two main research objectives:

- **RO 1: Provide methods, models and tools to help all necessary actors design effective TEL systems.**
- **RO 2: Provide adaptable models and authoring tools to facilitate the development of TEL systems, and thus increase their acceptability and use by teachers.**

Our research projects, aimed at these objectives, were all conducted with colleagues in the Social Sciences. The TEL systems were also co-designed and tested with pilot teachers and their students and last but not the least: we had fun!



CHAPTER 2

Methods, Models and Tools

Facilitating the design of effective technology-enhanced learning systems

Chapter 2

Methods, Models and Tools

Facilitating the Design of Effective Technology-Enhanced Learning Systems

Contents

1 Introduction

This chapter focuses on our efforts to achieve the first research objective, which is to provide methods, models and tools for designing effective TEL systems (*Figure* 2.1). It will be recalled that this research objective corresponds to challenges in our three main research branches. For Serious Games (SGs), the challenges are choosing the right game mechanics and integrating them correctly into the educational content (C1[SG]) and proving the effectiveness of these game mechanics which are constantly called into question in educational contexts (C2[SG]). For Mobile Learning (ML), the challenge addressed is to use geolocation and augmentations, available thought smartphone sensors, to foster authentic situated learning (C1[ML]). And finally, for innovative Human-Computer Interactions (CHI) for learning, the challenge concerned here is to choose the appropriate technology according to the educational objectives (C1[CHI]).

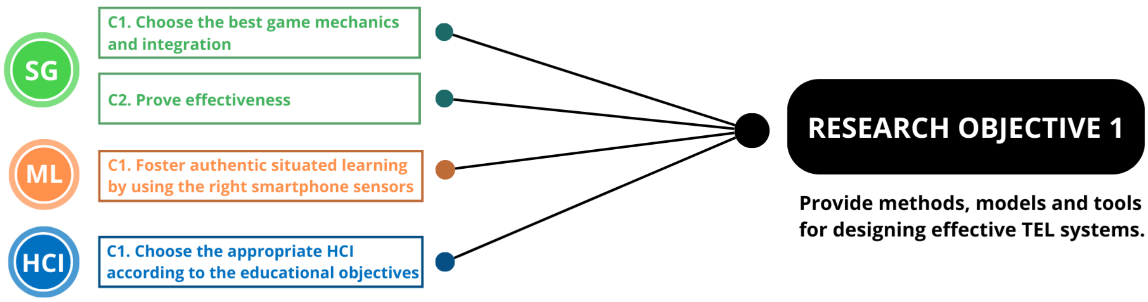


Figure 2.1: First research objective

We try to achieve this first objective by focusing on three main research axes. First of all, we have led several exploratory projects aimed at **identifying the best game mechanics, ML and HCI to enhance learning**. These projects have allowed us to explore the potential of innovative TEL systems in specific domains in order to provide design guidelines for future research. We have also proposed a practical implementation of the Design-Based Research method to find the appropriate game mechanics, ML and HCI with the help of teachers and other stakeholders.

The second axes we have pursued is to **help teachers find existing TEL systems**. Even though this is not strictly related to designing effective TEL, existing systems can be reused in new educational contexts or provide inspiration for the design of new TEL systems. It is therefore in line with our first objective. To be more precise, we will focus on helping teachers find one specific type of TEL systems: SGs. We have developed an automatically-updating SG catalogue with a data extraction model capable of scraping information from websites. This catalogue can also be used by researchers to find existing SGs and analyze them to build on this experience. As you will see, finding existing SGs is currently not that easy.

The third and last research axes we have chosen is to propose a **training method to help teachers create their own TEL systems with the available resources and staff**. We primarily focus on the creation of SGs at a university level, but the proposed method could be used in other contexts.

2 Research context and questions

2.1 Understanding how game mechanics, ML and HCI can be used to enhance learning

Understanding how game mechanics, ML and HCI can be used to enhance learning is a tricky question that is far from being answered. In his book, Jesse Schell explains that game design is currently more of an art than a science (Schell, 2019). There is no unified theory of game design and no straightforward formula to make a game. He compares the current situation to that of the ancient alchemists. Before Mendeleïev discovered the periodic table that links all the elements together, alchemists would use a combination of methods learned through experimentation. These methods were incomplete, sometimes erroneous and mystical, but alchemists were capable of obtaining impressive results and it was their determination to understand the underlying mechanisms that led to modern chemistry.

This is pretty much the situation in SG design (essentially game design with an extra dose of educational complexity) but also for TEL design with innovative technologies such as ML and HCI. There is currently no unified theory. But do not get me wrong, the TEL community has been working hard on finding one and we already have a great number of **design principles** that can be applied. These design principles are the bricks that TEL researchers can build on to discover new principles and elaborate wider theories. Producing good quality bricks is essential and researchers in educational sciences have turned to a method called **Design-Based Research** (DBR). This method, developed in the early 2000s, is composed of several iterative cycles of design, testing, evaluation and reflection. It is fundamentally **user-center** (teachers are involved from the very beginning of the project) and **grounded in real world settings** (the tests are carried out in real classrooms) (Collective, 2003).

The use of DBR in TEL also takes inspiration from older methods, such as action research (Wann 1953) but also User-Experience design (UX-design), participatory design and co-design methods. However, DBR is quite vague concerning the ways that it can be used, especially for designing complex TEL systems that implicate many actors. Should all actors be implicated from the start? At what stage should the technology be introduced so as not to curb the imagination process?

We therefore have two research questions:
- **RQ1. How can we use game mechanics, ML and HCI to enhance learning?**
- **RQ2. What practical design method should we use to create effective TEL?**

To answer the first research question, we propose to participate in this epic journey towards a unified TEL design theory by adding a few bricks of design principles for specific educational contexts and objectives. Through three research projects, we have explored the potential of TEL systems for enhancing collaboration among middle-school students learning the basics of computer programming (**TurtleTable(t)** project), for facilitating the comprehension of fractions on a number line (**SMART-Fractions** project) and for helping professionals control their emotions in complicated situations (**TGRIS** project). After using the DBR method for these three projects, we also propose a practical implementation of this method for innovative TEL, by identifying the important work sessions and productions that should be carried out during each phase and the actors that should participate.

2.2 Providing an access to existing Serious Games

The objective of this second research axis is to help teachers use SGs in their class without having to create them, which is a very costly and time-consuming endeavor.

Today, more then 800 SGs are available, in a wide range of educational fields, from kindergarten to professional training (Morie et al., 2020c). And yet, there is no easy way to find them. Indeed, on a common search engine, one only finds well-referenced SGs, which are quite expensive and require specific equipment (e.g., a game console). Often teachers do not have this type of equipment in their schools and the SGs are not always suitable for their pedagogical needs (Marfisi-Schottman et al., 2011), (Palé, 2018). Teachers may also come upon a few SG catalogues, but these have several serious limitations.

One issue is that there is no common data offering a large selection and variety of SGs.

The four catalogues that presently provide more than 50 SGs also reference SGs that are not related to learning at all (but rather designed for advertising, politics or recruiting). For instance, the *SeriousGameClassification* catalogue provides 3 300 SGs, with only 12% educational oriented SGs, while the *MobyGames* catalogue provides 120 342 SGs, with only 0,2% addressing education. This makes it very hard for teachers to find educational SGs (Gibson et al., 2007). A second issue is that catalogues, that only list educational SGs, provide a limited selection because they only focus on one specific subject or specific user age. For example, *Vocabulary Spelling City* has 42 SGs *that focus exclusively on* English spelling. Similarly, catalogues provided by educational SG publishers such as *IKIGAI* (with 14 SGs) or *MIT Arcade* (with 7 SGs) only list the few SGs they have developed.

In addition, each catalogue uses its own metadata schema to describe the information about SGs and none of them meet teachers' needs. For example, the *SeriousGameClassification* catalogue uses the G/P/S (Gameplay/Purpose/Scope) schema (Djaouti, 2016). Gameplay provides information about the game's graphic and the type of game. Purpose details the targeted market (e.g., health, military, education, politics). Finally, scope refers to the age and category of the targeted users (e.g., students, professionals) (Alvarez et al., 2017). The *MobyGames* catalogue classifies games according to the platform (e.g., PC, Android, or Nintendo), the year of publication, the type of game (e.g., visual, board game or shooter) and the legal rating of the game (e.g., PEGI). It is clear that these classification criteria are of very limited use when one is interested in the pedagogical aspects of SGs. For instance, there is no information available about the discipline or the educational objectives. These metadata models, designed to describe mostly non-educational SGs, do not provide relevant information for teachers (Aouadi et al., 2015), (El Borji and Khaldi, 2014).

Finally SG catalogues need to be user-friendly. Many existing catalogues use limited searching tools. For example, in *SeriousGameClassification*, all filters are in checkbox format with predefined values, regardless of the information described. Offering only this format forces the user to check boxes among those available even if their values do not correspond to their real needs. For example, a teacher who wants SGs for learners aged 6 to 13 will have to check the boxes 3 to 7, 8 to 12 and 13 to 16. The search will then return SGs outside the required age range. Another example, taken from the *MobyGames* catalogue: the filters offer endless value lists, without the possibility of searching by keyword. To find SGs that work on tablets or smartphones, teachers need to go through the list of 270 platforms offered. In addition, the search filters disappear from the result page, forcing teachers to go back to the previous page to adjust the search if the results are not satisfactory.

All these issues can be summaries by three additional research questions:
-RQ3. What metadata schema is most suitable for educational SGs?
-RQ4. What models are needed to automatically extract information about SGs on the Internet?
-RQ5. What catalogue interface will best help teachers find existing SGs?

Our approach to tackling these questions is pragmatic. We have created a new metadata schema for SGs by merging several existing SG metadata schemas in the literature. With the help of teachers and, based on information provided by SG publishers, we then reduced the number of entries (initially more than 80) to a functional minimum (23) in order to encourage SG publishers to fill out this minimal information. We also developed an automatic indexing model capable of extracting information automatically from existing catalogues and web pages. Concerning the catalogue's interface, we have designed an original method allowing teachers to edit filters and decide on their type and position on the interface. All these propositions have been implemented in ***JEN-planet***, an automatically-updating educational-SG-exclusive catalogue with more than 800 SGs.

2.3 Helping teachers create their own innovative educational tools with the available resources and staff

Teaching needs to evolve towards using more active and interactive methods so as to keep students motivated and involved in school (Kurganovna et al., 2022), (Niemi, 2002). Many teachers therefore feel the need to change the activities they offer or the way they teach. Some of them have heard of SGs or Gamification through the media or publications. Educational escape games were a big hit a few years ago. Others hear of tools used by their colleagues or promoted by their school or university such as *Moodle* (e-learning platform), *H5P* (mini-game editor), *Moovly* (animated video editor) or *Wooclap* and *Kahoot* (voting systems on smartphones to use during lectures). But how to get started? What is the right educational tool? Who can they contact to get help? To create a SG, for example, teachers ideally need to work with a game designer and an entire team of developers, but where can they find such a team and how can they possibly pay for their services? Teachers often feel at a loss and need help identifying the resources and contacts they need before engaging on their quest. As we have scientific proof of the effectiveness of SGs, we believe it is crucial to encourage them.

This leads to two additional research questions:
- RQ6. What is the most efficient method to help teachers create their own innovative educational tools with the available resources and staff?
- RQ7. What guidelines can we provide to encourage teachers to get started on a SG project?

Seven years ago, the universities in the western region of France decided to merge (Université Bretagne Loire) to set up common services, including professional training. At that time, our lab was identified as a TEL expert and I was asked to set up a first training session to help university teachers create SGs. The training session, which we called ***Ludifik'action***, helped teachers create their own SGs with the available resources and staff members of the university. They objective is to help them create a prototype and test it with their students within five months. The type of SG was chosen based on each teacher's needs and constraints. Some would create card games, board-games, role-playing games or even simple digital games with free editors and tools found online. Even though the training session did promote SGs, some teachers created ML applications or used HCI with QRCodes. The training session, which still goes on today, produces all types of innovative educational tools, not necessarily digital TEL systems, and not necessarily SGs. It is obviously just a first step since the design of a proper educational tool requires several iterations, but the objective is to give the participating teachers a positive experience and motivate them to continue. As you will see, 35% of them did continue by perfecting their prototype, creating other educational tools or even by helping colleagues create their own tools.

In the middle of the first training session, the universities unmerged for political reasons, but I wanted to finish what I had started. The results were so unexpectedly remarkable that I decided to continue the year after. After seven years, with more than 100 teachers trained and 32 educational tools created, I believe we have perfected a training method that can be used by other trainers and in other contexts. We have also identified 10 simple guidelines to help teachers get started on their adventure.

3 Contributions

3.1 Game mechanics, ML and HCI to support learning

The research presented in this section tackles:
- **RQ1. How can we use game mechanics, ML and HCI to enhance learning?**
- **RQ2. What practical design method should we use to create effective TEL?**

As explained in the introduction, designing innovative TEL systems is not easy and requires more empirical studies and experiments to provide clear design principles and models. We have participated in this research by designing several innovative TEL systems with the **Design-Based Research** (DBR) method to investigate the effectiveness of game mechanics, ML and HCI for learning in various context. In the next sections, we will present three projects.

The **TurtleTable(t)** project uses game mechanics and tangible objects to encourage collaborative learning of basic computer programming in middle school. The second project, **SMART-Fractions**, uses game mechanics and Mixed Reality to teach fractions in primary and middle school (my third PhD student, Sofiane TOUEL is currently writing his thesis on this particular project). The last project, **TGRIS**, uses Virtual Reality in order to help adults better manage their emotions in complicated professional situations.

We will briefly present the findings for each project. What was the practical problem we wanted to address? What were the state of the art design principles that our work was based on? What is our proposed TEL system? And lastly, what are the new design principles (new bricks for the research community) that were developed?

Finally, after using the DBR method for these three projects (and the four other projects presented in the next chapter), we propose a **pragmatic implementation of DBR** with clear work sessions and productions for each phase. This implementation is specifically intended for TEL projects that use innovative technology such as Mixed Reality or Virtual Reality, which teachers are not familiar with.

3.1.1 TurtleTable(t): Collaborative game with tangible objects to learn the basics of computer programming

Practical problem
Computer programming was added to the official curriculum in French middle-schools in 2016 while the program to train teachers to computer programming only started in 2019 and there are still very few positions for recruiting such teachers. Consequently, computer programming is taught by teachers who are not trained and this will realistically still be the case for a while. There is an urgent need for course material and activities that can self-correct.

Such an early introduction to computer programming also aims at encouraging more girls to embrace careers in this field (Mannila et al., 2022). However, many children, and especially young girls, experience anxiety related to math and more generally scientific-related activities (Owolabi et al., 2014). It is therefore important to make this first contact with the field as enjoyable as possible

State of the Art
Teachers currently use computer programming activities provided in books. They mainly use block coding and unplugged activities, which can be done without a computer or special equipment. One example is the collaborative game *StupidRobot*. Played by three players, one pupil constructs an algorithm with "move forward", "turn-right" and "turn-left" cards, another executes it by pointing at the current card, and the last pupil makes the moves on a board or a tiled floor. Like this game, all unplugged activities are carried out in teams of two or three students, and collaboration plays an important role. Not only is collaboration an important skill in the curriculum, but it increases motivation and significantly improves student performance (Johnson et al., 1981), (Cassone et al., 2021).

Finally, several researches offer empirical evidence that the use of tangible objects on interactive tabletops fosters student motivation and may also enhance collaborative learning, especially for children who are used to learning by manipulating objects (Kubicki et al., 2015), (Schubert et al., 2012).

Propositions: TurtleTable(t), a collaborative game with tangible objects
TurtleTable(t) is a collaborative game inspired by the *StupidRobot* game presented above. The players need to move **pawns on a grid, following the instructions of the program** on the screen (*Figure* 2.2). The game indicates if the instructions were executed correctly or not, in real-time (the code line is colored green or red), thus allowing players to understand the principles of how a computer executes a program. Each time the pawn moves, it draws a line that, little by little, create a drawing (in reference to the *LOGO turtle*). The total number of errors is summed up and small animations appear as a reward when the level is completed without errors. This encourages players to think before acting.

The game offers 20 levels that progressively introduce algorithmic concepts (variables, loops and conditions). The difficulty increases as the codes become longer and concepts are combined (as in the last level shown in *Figure* 2.2).

In order to encourage collaboration between players, the game can be played with **tangible objects that are recognized by the screen**. The use of such objects have shown great potential for learner engagement and learning outcome (Kubicki et al., 2015), (Schubert et al., 2012). We also believed that the fact that each player has a personal object they need to manipulate, in turn, to advance in the game, would encourage collaboration. In *TurtleTable(t)*, the objects are used to move and turn the paws on the grid and the game is designed in such a way that the players need to coordinate their actions to progress. We developed several versions of the game for interactive tabletops, tablets and PCs, for 2 to 3 players. The game also works with tactile interactions (using fingers) or the mouse and arrows on the keyboard.

Experimentation
TurtleTable(t) was developed over three years of iterative cycles and testing in classes. The first version, called *TurtleTable*, was developed for interactive tabletops. The pilot teachers were so enthusiastic that we adapted the game to tablets, which are much more affordable. This forced us to rethink the entire interface but also to find new technical solutions to recognize tangi-

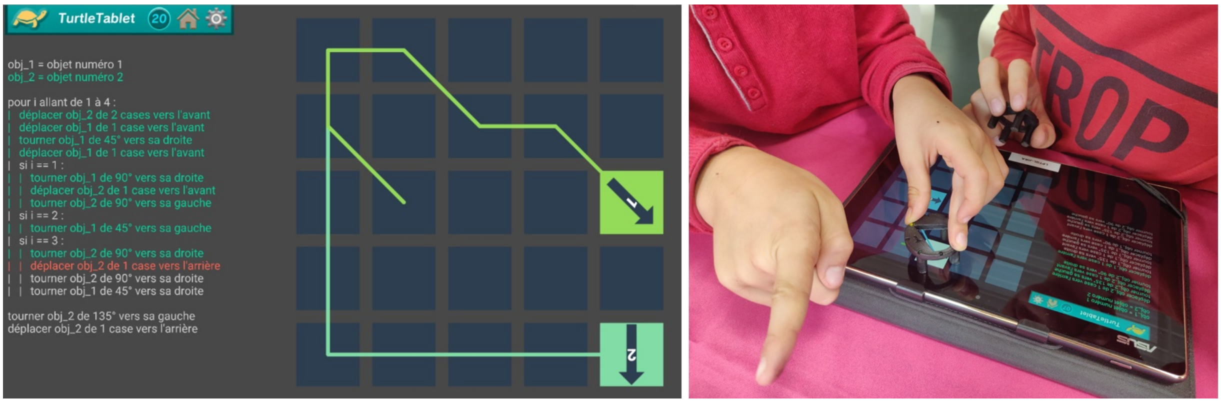


Figure 2.2: Interface and tangible objects for the TurtleTablet collaborative game

ble objects on the tablets' capacitive screens, which are very different from interactive tabletop screens. Comparative experiments were led with more than 300 students to analyze the effect of the interactions (tangible objects, tactile interactions, mouse and keyboard) and the size of the screens (tablet vs. interactive tabletop) (*Figure* 2.3). Some students even built and customized their own tangible objects, with a 3D printer and conductive paint, by following the construction guide. The students answered pre-test and post-test questions after playing the game (1-hour session). Interesting observations were also made after analyzing the interactions between players through videos and self-confrontation interviews.

Figure 2.3: Comparative studies led with TurtleTable(t)

Design principles

The experiments and results are described in detail in (Marfisi-Schottman et al., 2018). Here are the main design principles that were formulated based on the results of this project.

- The use of personal tangible objects **can encourage collaboration** among learners in situations where one student is in difficulty. The other students will be more likely to provide help by explaining, verbally, what the code means and the movements they should be doing instead of simply doing the movement themselves.

- The positive effect of personal tangible objects seems to apply not only to large interactive displays but also to **small affordable tablet screens**.

- The use of tangible objects seems to have **a positive effect on mastering the change of spatial reference system** that is a competency used in computer programming but also in geometry and logic.

3.1.2 SMART-Fractions: Mixed Reality game to apprehend the representation of fractions on a number line

Practical problem

Fractions are one of the most complex and challenging notions for children to master and can often lead to frustration and a revulsion for mathematics in general (Behr and Post, 1993). The ultimate objective is to understand the concept of fractions as **rational numbers** (p divided by q), that can be placed on a **number line** (Gunderson et al., 2019). However, this notion is too complex for children. Fractions are therefore usually first introduced as **parts of an object** (e.g., parts of pizza or cake). This simplified representation helps children grasp the concept but creates several didactic obstacles such as misunderstanding that a fraction cannot be greater than one. The fact that the objects are different can also lead to a misunderstanding of fraction equivalences. Indeed, a portion of pizza and a portion of cake do not seem equivalent, even if the pizza and the cake have the same weight. Children therefore need didactic tools that can help them understand the links between the various representations of fractions (Silver et al., 1983) to overcome these difficulties (Cramer et al., 2002). In addition, these didactic tools should be presented in a fun and empowering context, to motivate even the most reluctant children.

Several SGs have been designed to teach fractions in a fun way such as the *Potion Workshop*, a board game designing by math didacticians and used in more than 2000 French schools (Boissiere and Pelay, 2018). The objective of this game is to make a magic potion by finding the right fractions of ray, frog, spider and snake. The learners manipulate geometric shapes representing these four animals, and can test if their answer is correct by placing the pieces of ingredients on shapes drawn in the answer key grimoire. If the potion is correct, the pieces cover the entire shape exactly, without going over the lines or leaving a visible section. Even though this validation method is ingenious, it limits the combination of math activities that can be proposed and the teachers that use this game felt the need to constantly help students by providing additional feedback that could not be given by the board game (Pelay, 2019). In addition, the *Potion Workshop*, like all the other fraction games we have encountered, only focuses on one form of representation (i.e., parts of an object) and does not help connect several forms (i.e., the number line). Yet, the Rational Number Project Collective clearly states that children understand fractions better when they are taught with several representations and by making connections between them (Cramer et al., 2002), (Behr and Post, 1993).

State of the Art

Based on previous research, Mixed Reality (MR) seems to be a good solution to all of these problems. First of all, this technology can provide immediate contextualized feedback (Andrea et al., 2019) and auto-correction (Palaigeorgiou et al., 2019) because it can recognize the game pieces chosen by the players and display virtual information on top of them. In addition, the fact that MR can be used with real objects facilitates learning, according to the theory of embodied cognition. Secondly, concerning fractions, MR can be used to display several forms of representation dynamically. It can recognize parts of an object (e.g., $\frac{1}{4}$ pizza) and immediately display another form of representation (e.g., rational number or a position on a number line) thus helping students make the connection. This design principle is already used in several fields such as 2D and 3D geometry (Andrea et al., 2019), (Liou et al., 2017) but not yet for fractions. Finally, MR can increase student motivation and engagement (Chen, 2019), which could reduce math anxiety.

Proposition: The Magic Cauldron Mixed Reality game

The *Magic Cauldron* is a MR SG for learning fractions. It is intended for children from 9 to 11 years old and provides a 30 to 45-minute game scenario that can be played in autonomy. The scenario puts the players in the shoes of a sorcerer's apprentice who discovers a magic cauldron. Unfortunately, Arkan, a devilish creature, freezes the cauldron's magic and the children have to recalibrate it by completing several math activities. As shown in *Figure* 2.4, learners manipulate game pieces that are sections of geometric shapes, representing four types of animals: ray, frog, spider and snake. These game pieces are inspired by the *Potion Workshop* presented above. The experts in math didactics who designed this game participated in our project. Our intention was to keep the same game pieces to help students transfer the knowledge acquired on fractions with the board game to the next part of the curriculum: the number line. When the game pieces are placed in the cauldron, under the tablet, augmentations appear on the screen such as the value of the piece (e.g., "1/4") and the equivalent section on the number line below (e.g., a quarter of the number line from 0 to 1). Depending on the exercise, the values displayed at the beginning and end of the number line, called the "magimeter", can vary (e.g., 0 to 1 or 0 to 2), and it can also be broken down into sections (half, third, quarter, etc.). Students can ask Ekko, the little ghost who has been guarding the cauldron for 1000 years, for help at any time, by clicking on the "?" button. These aids were defined by the pilot teachers after testing the game with a first class.

The game consists of three types of learning activities (*Figure* 2.5). In the first type of activity, the children need to place a fraction on the number line. If they need help, they can use the game pieces (a representation that they are familiar with). When the pieces are placed in the cauldron, the equivalent section appears on the number line (red section in the first image of *Figure* 2.5) and the learners simply have to move the cursor to the end of it. The second activity follows the same principle. However, this time, learners cannot use the ingredients. Instead, they can divide the number line in 1 to 10 sections (not all options are always available). When children move the cursor on the number line, the application shows, in Augmented Reality, the shapes of the ingredients in the cauldron (same shape and size as the real game pieces). Finally, the third type of activity consists in finding and placing the right ingredients in the cauldron to match the value indicated by the cursor on the number line. Learners need to accomplish six exercises for each of these activity types. They gradually become more difficult, including fractions greater than one.

Figure 2.4: The Magic Cauldron Game material

Experimentation

Several experiments have measured the impact of the *Magic Cauldron* on learning. The first helped adjust the activities, simplify the game material and identify the moments when the students potentially needed help in order to create the feedback provided by Ekko. The second involved 228 students in three different schools. It was a comparative study to measure the level of progression among students who used the *Magic Cauldron* and among those who were in a classic learning setting. The last experiment took place over a period of several months with the same students. The objective was to see if the teachers would reuse the SG and how.

Design principles

The experiments and results are described in detail in Touel et al. (2023) and in the PhD thesis Sofiane TOUEL is currently writing. Here are the main design principles that were discovered during this project.

- The use of Mixed Reality **helps learners progress in the comprehension of fractions** as well as a classic course, provided by a teacher, does.
- The use of Mixed Reality and game mechanics **reduces math anxiety** as much as a classic course.
- The feedback and automatic corrections provided by Mixed Reality **give learners more** autonomy than in a classic course.

Figure 2.5: Three types of activities for learning fractions in the Magic Cauldron

- The use of a storyline and endearing characters makes the learning process **more enjoyable for learners** than in a classic course.

3.1.3 TGRIS: Authentic Virtual Reality simulation for emotional management in professional situations

Practical problem

In France, **pedagogical counselors** meet with novice teachers two to five times a year. They usually observe a teaching session and discuss what can be improved during a counseling session. However, when faced with displays of aggression, defeat or even tears (which happens about 20% of the time) some counselors feel destabilized and powerless. In 2014, 15 pedagogical counselors in the Nantes region took the initiative of sharing their experience in order to solve this problem, in collaboration with a Social Science research laboratory (CREN). They started recording and transcribing the parts of their counseling sessions that they considered as problematic. The analysis of these transcripts showed that the problem came from **their difficulty to understand and deal with the emotions displayed by the novice teachers** (Vinatier, 2015). In addition, dealing with someone else's emotions is complex because they inevitably **trigger our own emotions**. This is due to the mirror neurons effect identified by Rizzolatti et al. (2007). Emotions can also be very difficult to express because they are made of multiple intertwined mechanisms and related to **subjective experiences** (Cahour, 2008). Learning how to deal with someone's emotions therefore implies being capable of identifying and understanding one's own emotions.

Unfortunately, the professional training program for pedagogical counselors in France does not help them deal with emotions. The transcripts do not contain any information about the teacher's posture, gestures, facial expression or voice intonation, which are all essential in identifying emotions. The counselors felt the need for a new approach to help them recognize and deal with the emotions at stake during counseling sessions, both those of the novice teachers and their own. But how can one simulate realistic situations and generate emotions?

State of the Art

In the field of TEL, numerous researchers have proposed models and tools to automatically identify and represent students' emotions on dashboards for teachers (Leony et al., 2013), (D'mello and Graesser, 2013). *EMODASH*, for example, is a multimodal dashboard that helps teachers identify and take into account the emotions of their students (remote teaching) when writing their weekly reports (Ez-zaouia et al., 2020). In these research projects, the tools detect and show the emotions to the teachers. This method is not adapted to our context because the pedagogical counselors need to feel the emotions themselves in order to identify them and find a way to deal with them.

Virtual environments, such as *VTS Editor* aim to simulate realistic situations to improve professional skills (Lucas et al., 2013). In particular, **Embodied Conversational Agents** are often used to practice communication and interview skills. However, these interview simulations are far from authentic. Indeed, the learners alternatively watch a virtual agent or a video of a real actor and then choose a predefined answer. This has three major disadvantages for teaching. First of all, the learners do not work on their oral communication skills. Second, they do not work on constructing their own sentences and finally, the learners do not practice their non-verbal communication, such as intonation, posture or facial expressions.

ViTA (Burke et al., 2018), *TARDIS* (Anderson et al., 2013) and *MACH* (Hoque et al., 2013) offer much more natural interactions. These systems allow learners to train for job interviews by freely formulating answers to the questions of a virtual recruiter. These systems are capable of detecting certain key words to adapt the interactions. However, this logic only works for simulating interviews where the agent leads the conversation and there is only a slight need to adapt the reactions to what the learner says.

Virtual Reality (VR) is the latest breakthrough in interview simulations. VR headsets allow immersive and emotional simulations to be created. Several researchers have proven the effectiveness of such environments for teaching prompt decision making in stressful environments (Ponder et al., 2003), helping people with psychiatric disabilities train for job interviews (Bell and Weinstein, 2011) and helping people overcome their social phobia (Brinkman et al., 2012). These studies show that VR simulations are capable of triggering emotions that are very similar to those felt in the real world settings. In order to create authentic simulations that trigger these emotions, the virtual agents and the elements of the virtual environment are piloted, in real time, by a teacher or a therapist.

Proposition: TGRIS – Teacher-Guided Realistic Interview Simulator

The goal of *TGRIS* (Teacher-Guided Realistic Interview Simulator) is to allow pedagogical counselors to experience problematic counseling interviews. Ideally, these simulations will help them relive emotions they felt in similar situations and, with the help if their peers, find a way to deal with these complex and subjective feelings. It is not intended to replace either the analysis of the transcribed interviews or the role-play sessions that are currently used to train counselors. As shown in *Figure* 2.6, the pedagogical counselor wears a VR headset and talks directly to the embodied conversational agent (playing the role of a novice teacher). Before starting the simulation, the trainer chooses the appearance of the virtual agent and selects a context (e.g., the teacher is not paying attention and the kids are climbing on the tables). Before starting the simulation, counselors are given time to remember a real similar situation that they were confronted with, in order to immerse themselves in the simulation. The other counselors observe the simulation which will be analyzed collectively during the debriefing session that follows each simulation.

During the simulation, the virtual agent's reactions are triggered, in real time, by the trainer, through the control interface. The trainer controls the sentences, the non-verbal reactions such as crossing arms, raising shoulders or looking down and the emotions displayed by the agent

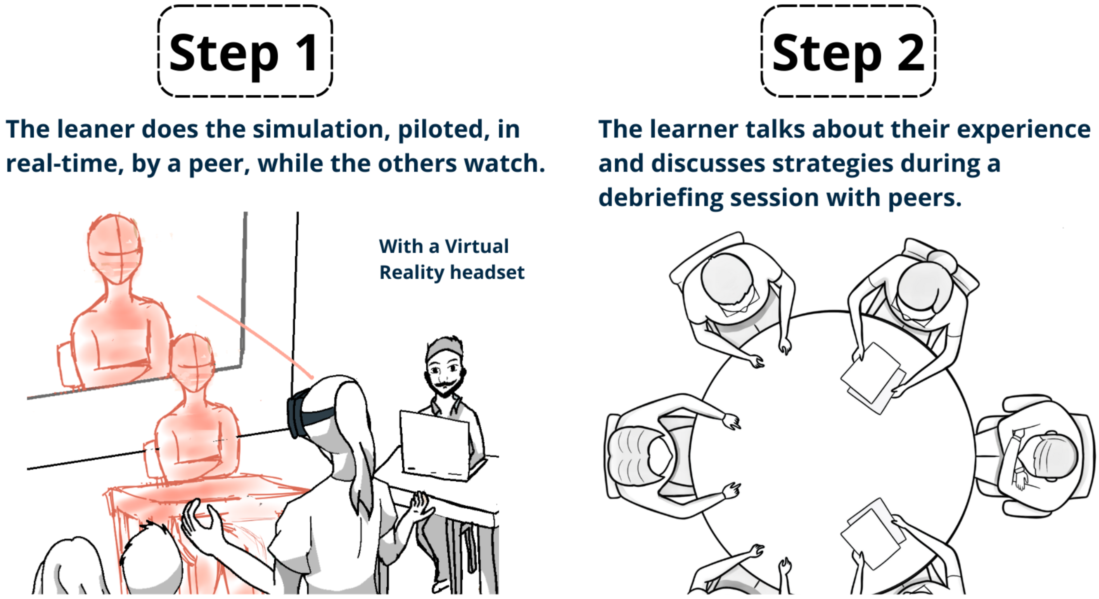


Figure 2.6: Use of TGRIS for professional training

(anger, anxiety, panic, joy or sadness). In order to simplify the control interface, the sentences are grouped in six categories. For example the category "refusal" contains sentences such as *"I'm tired of such questions; you should be telling me."* The trainer can add new sentences as well as multi-modal interactions (sentence with the associated emotion and gestures) by editing a text file. All the content (sentences, gestures and emotions) available in the control panel were provided by the counselors themselves. They spent several months transcribing and analyzing more than 15 real interviews that were considered problematic, in order to extract the questions or answers that triggered these problems. *TGRIS* was used in the context of several peer-training sessions: these are led by a group of experienced counselors who have analyzed their own practice for over three years. They played the role of the trainer and spontaneously decided to play this role by groups of two (*Figure* 2.7).

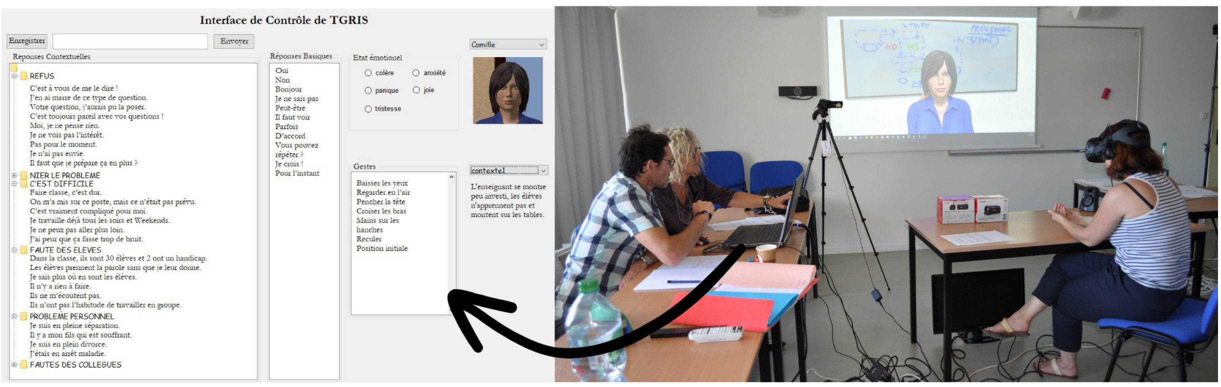


Figure 2.7: TGRIS Control interface, configured and controlled by peers

The virtual agent was developed with the *GRETA* system (Pelachaud, 2009). It has the specificity of providing a very large pallet of multimodal emotions, combining the tone of voice, facial expression and body language. In addition, the *GRETA* agents react to the sound of the learner's voice by nodding and shifting eye contact, giving the impression they are really listening. Thanks to these features, the virtual agents convey emotions and seem to have their own personality.

Experimentation
TGRIS went through four iterations of development and experiments from 2018 to 2022. The experiments took place every year, in June, during the counselors' professional training session. In total, 32 counselors tested *TGRIS*, including six expert counselors who also played the role of the trainer and piloted the agent. We led comparative studies between *TGRIS* simulations and the role-playing sessions the counselors usually use, but also between a VR and a screen version of *TGRIS* to measure if the use of a VR headset was really worth the extra cost and setup time.

Design principles
The experiments and results are described in detail in (Marfisi-Schottman, 2023). Here are the main design principles that were discovered during this project.

- Configuring a simulator with sentences and gestures extracted from real problematic situations enables **learners to relive emotions** they have felt before.
- The fact that the simulator only contains problematic situations and the virtual agent delivers them with no social filter creates **much harsher and destabilizing simulations** and this leads to richer debriefing sessions with peers.
- Virtual Reality helps **immerse the learners in the simulation**. They feel more emotions and are capable of better identifying them and hence reflecting on them during the debriefing session.

3.1.4 Design method for identifying the adapted technologies and using them to their full educational potential

The three projects presented above (TurtleTable(t), SMART-fractions and TGRIS), and the four projects that will be presented in the next chapter, all followed the **Design-Based Research (DBR)** method. However, all the articles and books we found on this method are very theoretical and do not offer practical guidelines as to how researchers and teachers should organize themselves. As presented in *Figure* 2.8, the DBR method is typically presented as four iterative phases (Reeves, 2006), (Wang and Hannafin, 2005), (Scott et al., 2020), (Sanchez and Monod-Ansaldi, 2015):

- 1. **Reflect**: analysis of practical problems and existing tools by researchers and teachers.
- 2. **Co-design**: collaborative design and development of solutions informed by existing design principles and technological innovations.
- 3. **Test**: iterative cycles of experimenting and refining of solutions in practice.

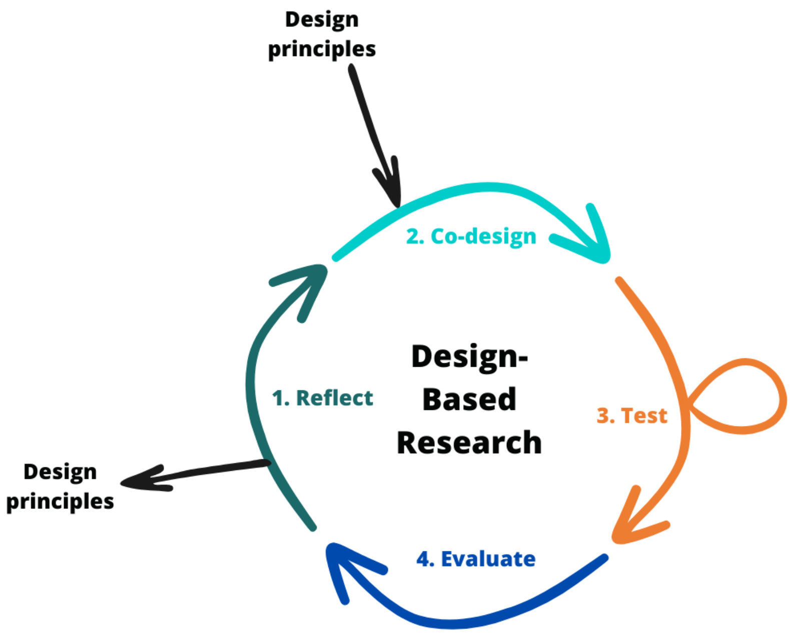


Figure 2.8: Basic phases of Design-Based Research

- 4. **Evaluate**: reflection to produce design principles and enhance solution implementation.

All the authors also emphasize that DBR is **user-centered** and should take teachers into account, from the very beginning of the project and during each phase. Researchers and teachers need to be united as a team that shares the same praxeology (shared discourse on practice) (Aldon et al., 2013). The DBR theory also insists that the test (phase 3) should be carried out **in schools**, under real-life conditions.

However, no practical guidelines are provided to identify important work sessions or an indication of what should be produced or accomplished at each phase. The ideal number of teachers and researchers or tests is not clear either even thought this could facilitate the entire process. Without having the pretension of revolutionizing this method, we therefore propose the pragmatic implementation of the DBR method we used and perfected during these seven projects. This is presented as a set of recommendations that can be used for TEL projects. As you will see in the following chapter, we will also propose four guidelines for designing authoring tools.

Pragmatic Implementation of Design-Based Research

First of all, let us set the perimeters of our proposal: the objective is to offer a practical implementation of DBR for TEL research that focuses on digital tools that are complex for teachers to grasp such as Mixed Reality or Virtual Reality. In accordance with Reeves' definition, we also believe that DBR is best suited for taking risks and discovering new ways of using technology for education (Reeves, 2006) rather than for testing existing theories. Finally, on a more controversial note, we also encourage developing several prototypes to lead comparative tests and evaluations. Most DBR definitions prone developing the design option that is favored by researches and teachers but understanding one option deeply will not allow the researcher to know whether another option might be even better. If there is no other prototypes, the first option should, at least, be compared with the classic teaching method (Reeves, 2006).

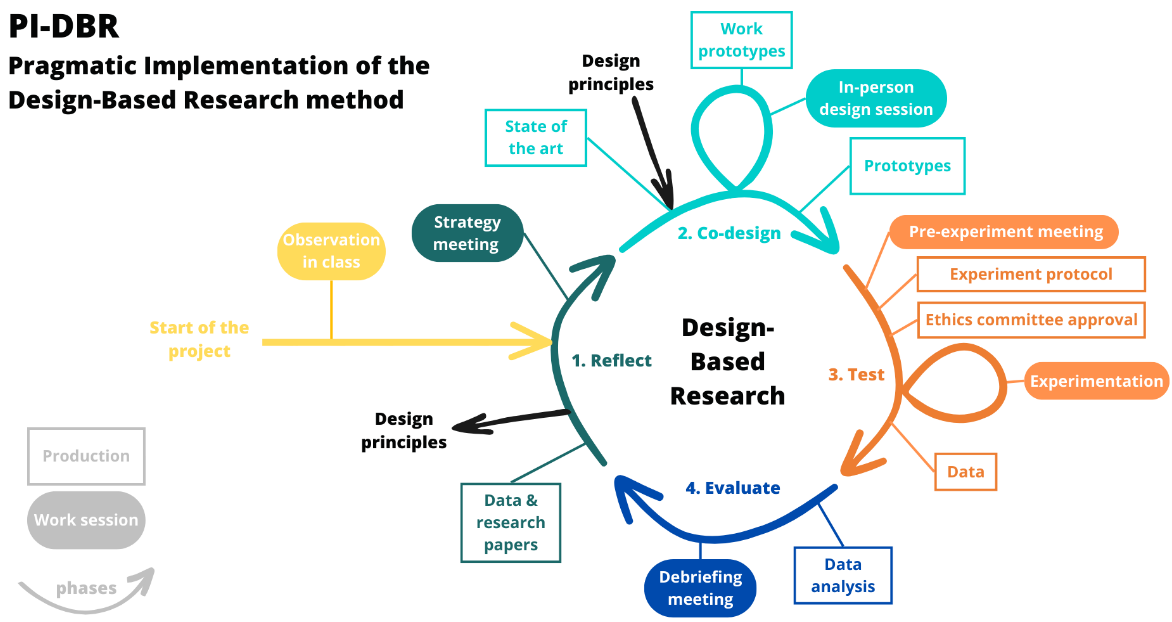


Figure 2.9: PI-DBR, a Pragmatic Implementation of the Design-Based Research method

Our **Pragmatic Implementation of DBR** (PI-DBR) is presented in *Figure* 2.9. It is composed of the same phases as DBR but provides more details on the work sessions and productions expected for each phase. *Figure* 2.10 also provides guidelines for the number of actors that should be implicated in each of these phases.

- **The project starts** with an observation session, in class, to help researchers understand the problem and the context in which the TEL system will be used.
- **Phase 1. Reflection** then starts with a *strategy meeting* during which the team needs to decide on the objectives of the project. This is when the project should be stopped if the researchers do not see any potential for an innovative TEL system to improve the given problem. In our experience, this is quite often the case. For example, teachers have sometimes come to us asking to create custom video games, even though it was clearly not adapted to the context or the educational objectives. Other times, we could provide them with perfectly adapted solutions that already existed but there is no need to continue if the situation is not research material.
- **Phase 2. Co-design** proceeds with a *state of the art* to find similar TEL systems but also to identify design principles that were found during other projects. Then comes several iterative cycles of *in-person* design sessions during which the researchers and the teachers try to find one or several ways of using technology for the given problem. We noted that it was very important to come to these sessions with *work prototypes* to help teachers grasp what could be done with the technology. This session should also definitely be done in-person so as to enable teachers to see and manipulate these prototypes, but also to encourage social

bonding. At the end of this phase, which can go on for 2 weeks to 5 months, one or more *functional prototypes* are produced.

- **Phase 3. Test** starts with a *meeting to discuss* the experimentation. This is important to determine the dates, the people involved (just teachers or also their students and parents if the students are minors) and, of course, the *experiment protocol*. The latter should also be written down in a document and sent to the *ethics committee for approval*. The *experiment* then takes place, several times if there is more than one experiment terrains and *data* from the questionnaires, videos, usage tracks and interviews are collected. The duration of this phase depends on the nature of the TEL system but also on the nature of the experiment (short or long term), but it usually lasts from 1 to 4 months.

- **Phase 4. Evaluate** starts with a data analysis by the researches and teachers and everything is discussed during a *debriefing meeting* as soon as possible afterwards. The type of analysis depends on the research hypothesis at this point in the project and the collaboration dynamics between researchers (one potential tension presented in chapter 1). We suggest combining qualitative and quantitative analysis and even duplicating some measures if necessary so all the partners have data to process. This phase should take place no more than 2 weeks after the experiment so as not to forget any observations that could be relevant. Lengthy video analysis for example can be finished and discussed later.

- Finally, we get back to **phase 1. Reflect** during which the team takes time to reflect on their design process, the developed TEL systems and their impact on learning and teaching in order to write *data papers and research articles* that present the identified *design principles* during this first cycle. The team gets back together to start a new cycle with a strategy meeting to discuss the next moves that can be made given the funding and time left at their disposal.

You might have notices that we did slightly tweak the DBR: we added an iterative cycle to phase 2. Co-design. This seems important for two reasons. First of all, even if the use of the TEL system can be adjusted by teachers, our experience shows that it usually requires some redevelopment which is very difficult to do on the fly, during the test phase. The second reason is related to the fact that the test phase is, by far, the most complex to set up. The teachers need to be available physically and mentally, the timing needs to fit with the official class curriculum, the authorizations need to be signed and the experiment protocol validated by the ethics committee. These occasions are therefore rare and precious (no more than a few times a year), so it is more effective to do more preparatory iterative cycles during the previous co-design phase.

Gradually implicating actors in the iterative cycles of Design-Based Research

Collaborative work, especially complex design sessions to find original ideas, is best done in small groups of 6 to 9 (Hall et al., 2018). We therefore suggest starting with a small core group composed of researches and teachers (half of each if possible) for the first iteration of the DBR and then expanding to other researchers and teachers (*Figure* 2.10). The integrating of these new comers, especially teachers, is very valuable because they have a fresh insight on the problem and will spot obvious omissions and practical issues that are simply not visible to the core team anymore. We suggest implicating them during the test phase of the second or third iteration to measure if the way the TEL system is presented to a newbie is clear. If the TEL system is intended to be used by teachers in autonomy, this is also a good way to test if the presentation documents and the tutorials are clear.

Even though the end-users are the teachers, the learners also need to be taken into account as soon as possible in the process. This will depend on their age and their capacity to make abstraction of the non-finished parts of the prototype. For the TGRIS project, intended for adults, we implicated them from the start. Howerer, for the SMART-Fractions projects, intended for children, we waited for the 3rd iteration to have a game-looking presentable SG. We did implicate them earlier on, in the choice of the storyline and character types, by presenting them with several alternatives.

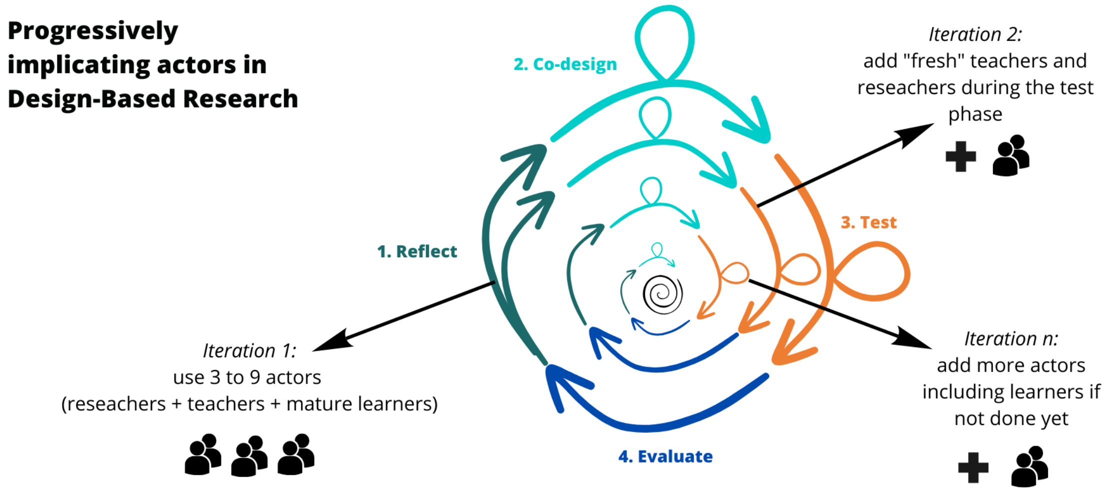


Figure 2.10: Gradual implication of researchers and teachers in the design cycles

3.1.5 Discussion and positioning of the work

Designing effective TEL systems has been the main preoccupation of the TEL community from the beginning. Our approach is high-risk and exploratory in the sense that we look for new ways of using technology for learning that have never been tried before. Of course, we try to reduce these risks by learning from previous projects and design principles used in similar context. The collaborative design method we chose to create these TEL systems is based on the DBR but we chose to combine this method with qualitative and quantitative comparative studies that are sometimes frowned upon by DBR purists. We argue that these methods are complementary: the first to find innovative ways of using technology to its full educational potential and the second to provide harder evidence of the effectiveness of the developed solutions.

3.2 JEN-planet: A Serious Game catalogue to help teachers find suitable existing Serious Games

The research presented in this section tackles:
- **RQ3. What metadata schema is most suitable for educational SGs?**
- **RQ4. What models are needed to automatically extract information about SGs on the Internet?**

- RQ5. What catalogue interface will best help teachers find existing SGs?

The research was lead in the context of Wielfrid MORIE's PhD (my second PhD student). The objective was to create a SG catalogue, for teachers, which updates automatically with the latest SGs found on the web. The goal is to help teachers access existing SGs, either to use them or simply to find inspiration in creating their own SGs. This catalogue is called *JEN-planet*. JEN stands for *Jeu Educatif Numérique*, which means "digital games for education" in French.

3.2.1 LGMD: an optimal metadata model for describing educational Serious Games

As presented in the introduction, current SG catalogues all use different description models and do not provide information about educational objectives and contexts, which are essential for teachers. On the other hand, researchers in TEL have proposed several metadata schemas to describe SGs (e.g., LOM, LOM-SG, MG, GPS), but these are usually extensions of the LOM standard that are composed of the 68 LOM fields plus an additional 10 to 20 fields. It is not realistic to ask SG editor to fill out all these fields, especially considering the fact that many are not relevant for SGs. We therefore defined the **LGMD (Learning Games Metadata Definition) schema** that contains only 23 description fields with a focus on the description of pedagogical features (*Figure* 2.11) (Morie et al., 2020b). These fields were obtained by combining several metadata schemas in the literature and by keeping only the fields relevant to educational SGs, with possible backward compatibility with the Learning Object Metadata (LOM) standard.

The proposed LGMD schema was validated at two levels. A first test verified that the 23 fields are sufficient to cover the information provided by SG publishers. The analysis of the information provided on 785 SG web pages showed that they only provide information for 17 fields out of the 78 or more provided by SG metadata in the literature and all of these fields are included in the 23 fields of LGMD. We made the decision to keep the addition 6 fields, for which information is never provided, because they are important to teachers and we wanted to encourage SG editors to fill them out. For example, none of the editors provide information for the knowledge validation field (list of competencies or skills that can be acquired by playing the SG). A second validation, with 17 teachers, verified that the fields are useful and sufficient to search for SGs that meet their pedagogical needs. This was done with co-design sessions and questionnaires in which they were asked to identify what information they needed to find and choose SGs for their class. These two validations show that LGMD offers an optimal number of fields: sufficiently numerous to cover the information relevant to teachers, yet not so many as to discourage SGs publishers from filling in this information.

3.2.2 ADEM: an automatic indexing model for Serious Games

In order to find and update the SG database automatically with new information, we have come up with the **ADEM (Automatic Description Extraction Metadata) model**. This is an automatic SG indexing model described in detail in Morie et al. (2020a). It collects information for each of the 23 fields of the previously presented LGMD metadata schema by scraping and analyzing the text on websites. The ADEM model consists of five major steps (*Figure* 2.12). The first step consists in collecting SGs through their web pages. Then, in the next two steps, the content in the HTML tags of the web pages is processed to select only the text blocks containing the SG description information and delete publicity and general information about

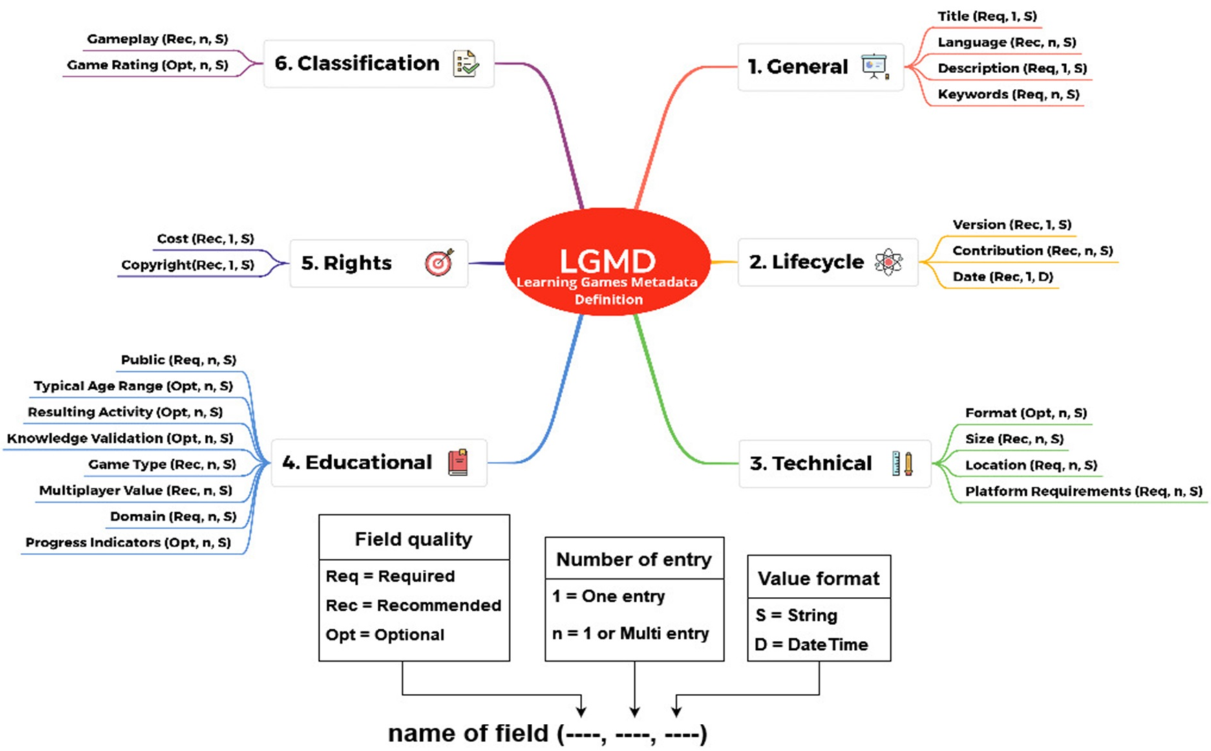


Figure 2.11: Learning Games Metadata Definition (LGMD) model

the SG publisher. Finally, the two last steps allow to extract the keywords describing the 23 metadata fields (i.e., title, language, location, public, domain, cost…) as well as the image of the SG. This information can then be modified by a human, in case the automatic extraction was not accurate or complete.

The ADEM model collected information on 785 web pages with SGs. The model's performance was evaluated with metrics such as precision, recall and F-Measure. The relevance of the information was also evaluated by 15 teachers on a representative selection of SGs. They compared a sample of websites to check whether the information automatically extracted by ADEM matched the information they were able to find by reading the pages. The evaluations resulted in an accuracy level of over 82% and a relevance score of over 4/5.

3.2.3 UDID: an interface design method by teachers

The *JEN-Planet* interface was designed with the assistance of 17 teachers, following the UDID (User-Driven Interface Design) method we proposed. Inspired by user-centered design (Dabbebi et al., 2019), this method proposes five steps with specific material (Morie et al., 2020c). This material consists of a white A3 sheet of paper, cards representing all available filters of the LGMD metadata schema in different formats (e.g., checkboxes, drop-down list) and empty post-its used to represent the thumbnails of the SGs found after the search. Following the steps of the UDID method, the teachers first decided where they wanted to put the main interface zones on the A3 sheet (search, sort and results zones). They then chose the filter cards to put on the interface. This step is particularly important as it involves identifying the most important of the 23 filters

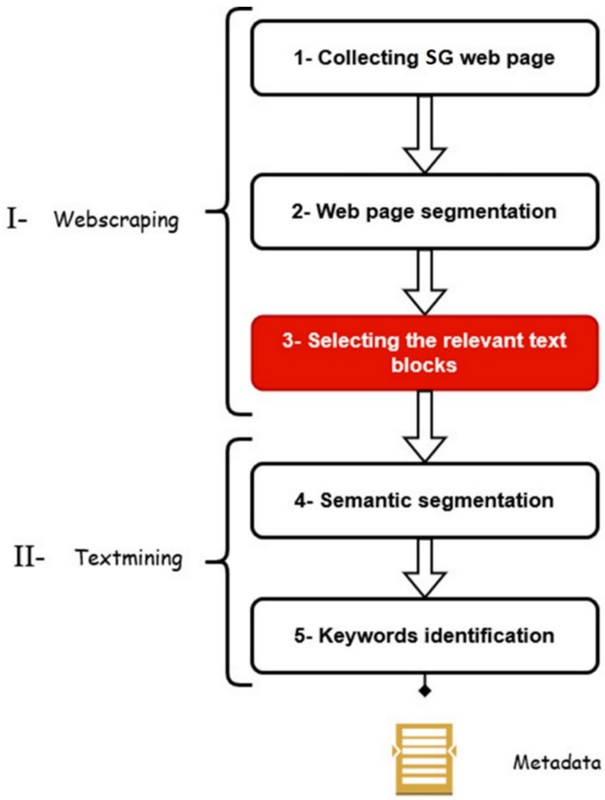


Figure 2.12: Steps of the ADEM (Automatic Description Extraction Metadata) model for SGs

available and their formats. The size ratio between the cards and the sheet recreated the layout of a web interface. This helps to identify which filters are most important. In the next step, the teachers chose the layout of the search results and represented, on post-its, the information they found relevant to describe the SGs that were found after the search. A debriefing, concluded after the design session, allowed teachers to explain and discuss their choices. Thus, the UDID method allowed 17 teachers to design several mock-ups of SG catalogue interfaces (*Figure* 2.13). The paper Morie et al. (2020c) describes, in detail, how all these mock-ups were used to design the final interface (*Figure* 2.14).

When the user clicks on the title or image of the SG, the catalogue opens a detailed description page. This page repeats the information provided in the thumbnail and adds information about the additional filters. If the teachers wants to learn more or test the SG, they can click on the red link, at the bottom right, which leads to the original page where the information was collected. This link opens in a new tab to keep *JEN-Planet* open. The interfaces shown in *Figure* 2.14 are from the current version of *JEN-Planet*, available at `https://jen-planet.univ-lemans.fr`.

3.2.4 Experimentation with teachers

The contributions presented above were put to the test with 50 volunteer teachers of various profiles. We set up a study to compare *JEN-Planet* with the two major catalogues in the literature,

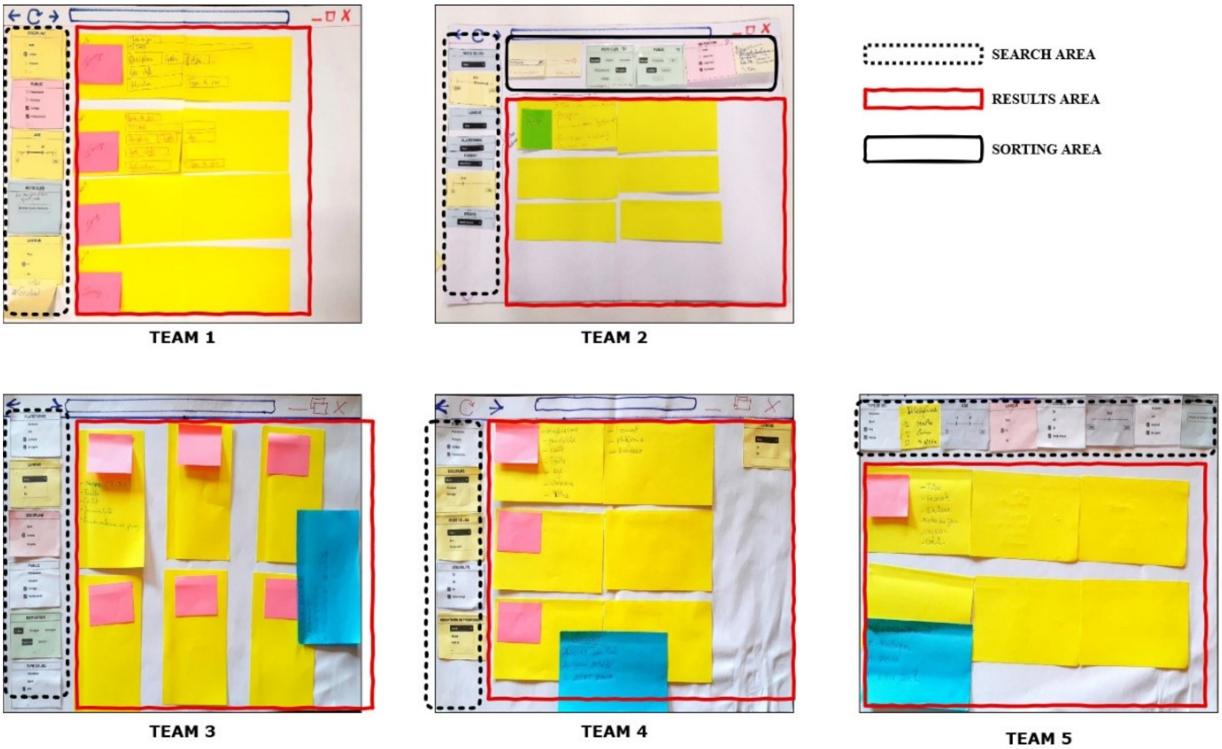


Figure 2.13: Interface mockups from the design sessions

SeriousGameClassification and *MobyGames*, because they contain the largest number of SGs (420 and 310 respectively) and are results of research projects (Alvarez et al., 2017), (Palavitsinis et al., 2014). Each catalogue was evaluated according to three criteria. Firstly, we examined the **usability** of each catalogue to determine the level of ergonomics of the catalogue's interface. Then, we measured the **relevance** of the SG descriptions, to determine whether the information used to describe the SGs is understandable and complete for teachers. The third and last criteria was the **utility** of the catalogues, to find out whether teachers can find SGs that are suitable for their needs.

In terms of **usability**, the results show that *JEN-Planet* is better for finding SGs. The catalogue designed using the UDID method is ergonomic and intuitive for teachers (*Figure* 2.15). The scores of *JEN-Planet* range from "good" to "best possible" according to the SUS (System Usability Scale) interpretation. This user-friendliness was also emphasized by the participants during the debriefing. Nevertheless, teachers also raised some limitations. For example, several teachers noted that the keyword filter was not explicit enough. Others would have liked additional filters on the date or groupings by subject category for example. While we understand these requests, we feel that more filters would overload the interface. In addition, the catalogue allows you to add these criteria in the advanced search option. Finally, several teachers deplored the fact that the web page does not adapt well to smartphone screens. This would indeed be a useful improvement.

In terms of **relevance**, the results show that teachers found the information provided by *JEN-Planet* much more comprehensive and complete than the information provided by the other catalogues (*Table* 2.1). Let us restate the fact that *JEN-Planet* extracts data from the two other catalogues and several others so their databases are only partially the same. In addition, although

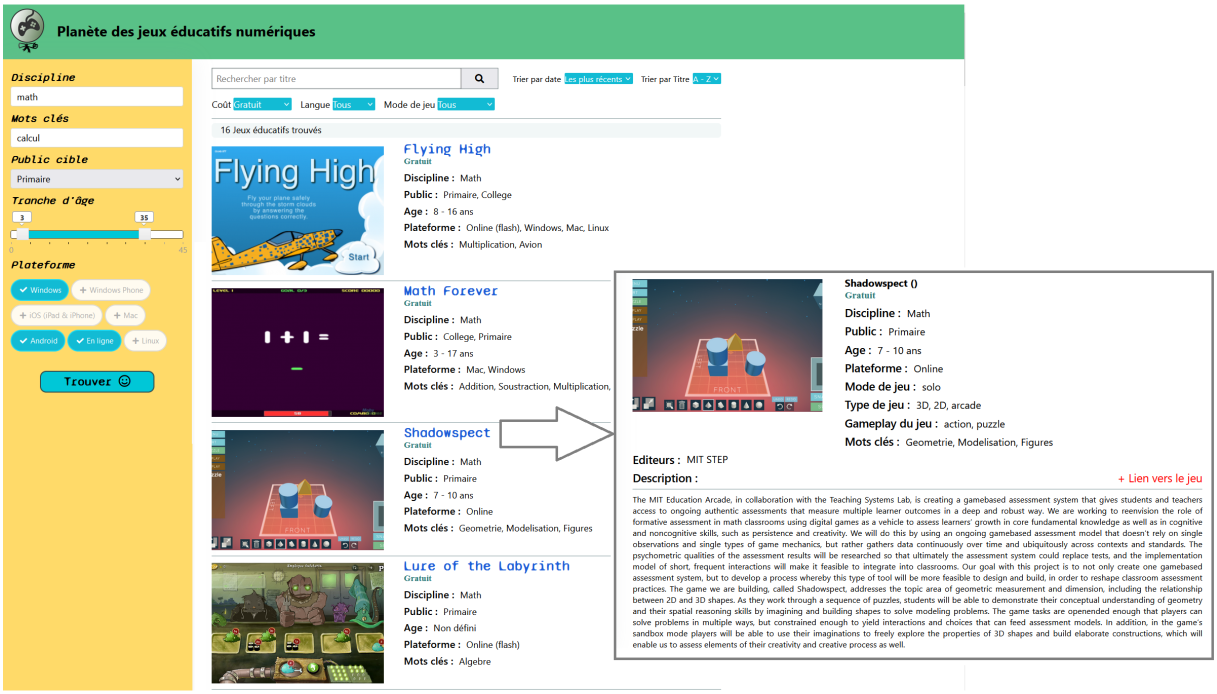


Figure 2.14: Catalogue JEN-Planet homepage

JEN-Planet scored average of 4.10/5 on completeness, its interpretation shows some downsides. Indeed, teachers indicated that information on "pedagogical objectives", "date ranges" or "language" was missing. As mentioned above, it is possible to search with these criteria in the advanced search options, but they are rarely provided by SG editors (less than 4% of the time). Therefore, adding these filters to the basic search options would not currently allow more SGs to be found.

Table 2.1: Average scores for the comprehensiveness and completeness of the information, provided by the SG catalogues

Catalogues	Comprehensive (/5)	Completeness (/5)
Jen-Planet	4.68	4.10
SeriousGameClassification	2.43	2.12
MobyGames	2.03	1.32

Finally, in terms of **utility**, *JEN-Planet* scores much higher than the other two catalogues. In the allotted 10 minutes, 42 teachers found at least 1 relevant SG (i.e., a SG they wanted to test) compared to only 16 teachers using *SeriousGameClassification* and 10 teachers using *MobyGames* (*Figure* 2.16). Moreover, the percentage of relevant SGs found is higher with *JEN-Planet*. The teachers found almost 50% of the search results provided by *JEN-Planet* relevant, while the data shows 11% for the other two catalogues (only 1 relevant LG out of 8 to 10). Furthermore, these catalogues contain many old non-educational SGs which may be obsolete in view of current computer hardware, unlike *JEN-Planet* which only contains recent SGs (published since 2008). In addition, some of the SGs identified by teachers as relevant, from *SeriousGameClassification*

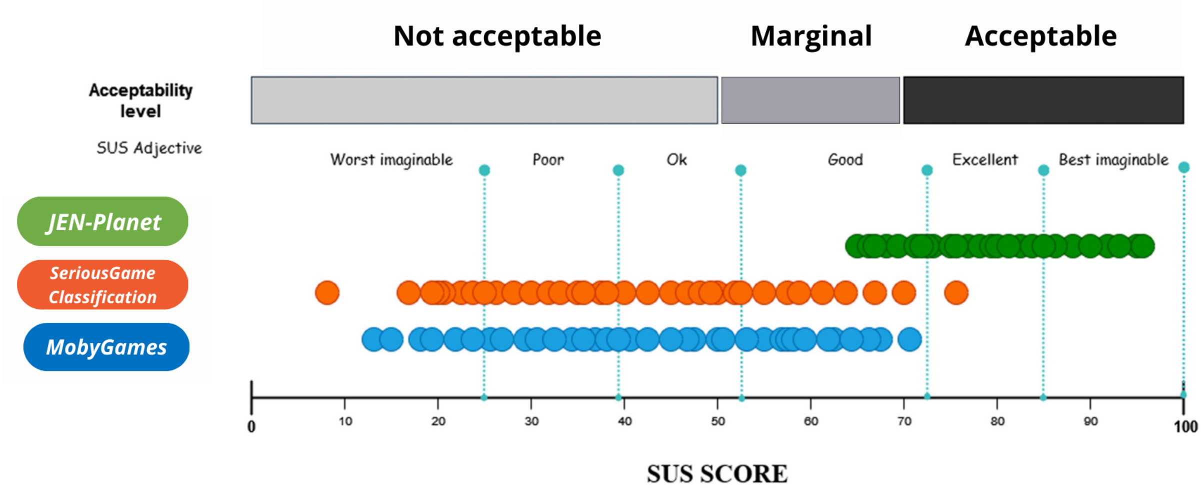


Figure 2.15: Distribution of evaluations by catalogue in the SUS score grid with interpretation

and *MobyGames*, are in fact non-educational games.

3.2.5 Discussion and positioning of the work

Sharing educational content is one of the main preoccupations of TEL research. The LOM was finally adopted as a standard (LOM, 2002) in 2002. Since then, countless LOM-extensions have covered the specificities and new types of learning materials (e.g., SGs), to include various countries (e.g., LOM-FR) or to take into account the lifeline (modification, sharing among teachers) of these learning materials (Broisin et al., 2005).

The problem with these extensions is that they only add more categories and description fields to an already very complicated LOM (68 fields) and let's face it, no one wants to fill in that many fields of information when they are depositing their learning content on a catalogue. Our approach is quite original as it aims at reducing fields to a reasonable number, one that editors will actually be willing to fill in (23 fields). The proposed extraction model can also help editors in the completion of these fields by automatically extracting the values from the text that describes a SG. We believe this proposition could also be used for other types of learning objects.

Nevertheless, the research carried out on *JEN-Planet* shows several limitations. First of all, the comparison of the catalogues is not as simple as it seems since the interface, the metadata and the database of SGs are different from one catalogue to another. However, with the information extracted from *SeriousGameClassification* and *MobyGames*, *JEN-Planet* still shows better results in terms of relevance, usability and utility. The second drawback is the fact that the catalogue does not provide teachers with the possibility of giving feedback on the SGs they have tested, nor does it allow them to add their own SGs. Ideally, such a catalogue should enable users to add not only the final SG but also the source codes and work documents so that other teachers can modify them. DIY kits and non-digital SG material should also be present in the catalogue. But, most importantly, *JEN-Planet* lacks a community to update the database, report SGs that do not work anymore, update the data or even work on improving the meta-data itself. Without a proper community to support its use, it is yet another abandoned research prototype.

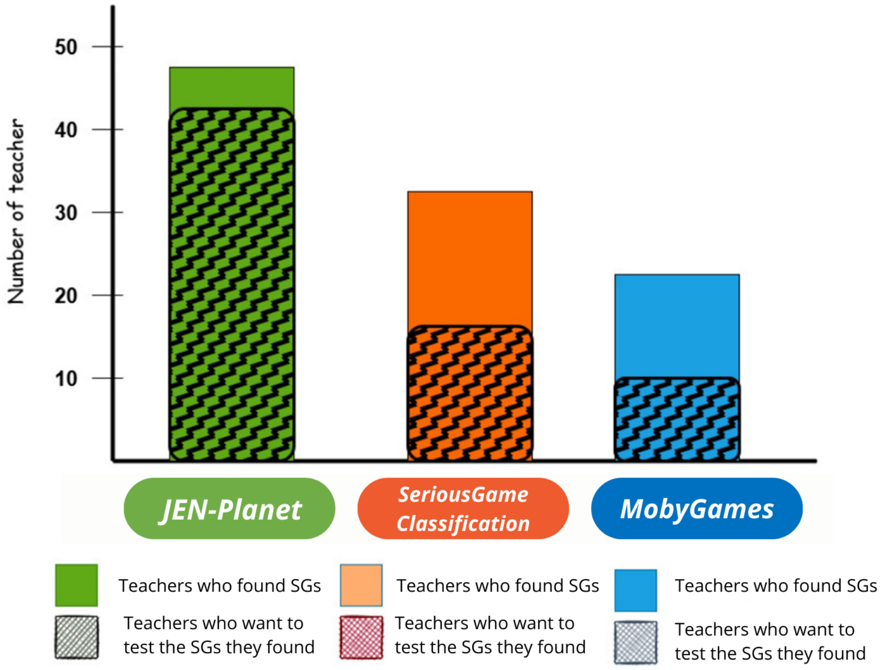


Figure 2.16: Proportion of the 50 participant teachers who found SGs and want to test them

3.3 Support and follow-up method to help teachers create their own educational tools

The research presented in this section tackles:
- **RQ6. What method is most efficient to help teachers create their own innovative educational tools with the available resources and staff?**
- **RQ7. What guidelines can we provide to encourage teachers to get started on a SG project?**

This research was done in the context of a professional course, called Ludifik'action that we did not initially consider as a research project. After teaching this course for seven years, in various contexts, we identified a number of rules and guidelines that could be useful to the research community. These contributions are therefore more of a practical "return on experience" rather than findings on models and theories of SG design, even though some of the findings coincide.

3.3.1 Training and follow-up method

Ludifik'action is a professional course to help university teachers create custom-made SGs (digital or not) (examples in *Figure* 2.17). This course teaches them the basics of game design and puts them in contact with experts and resources that can help them in this adventure. We have conducted seven sessions of this course, with a total of 104 participants.

The complete 5-months training program consists of two full days of face-to-face training with all the teachers. Between these collective sessions, an individual follow-up session takes place

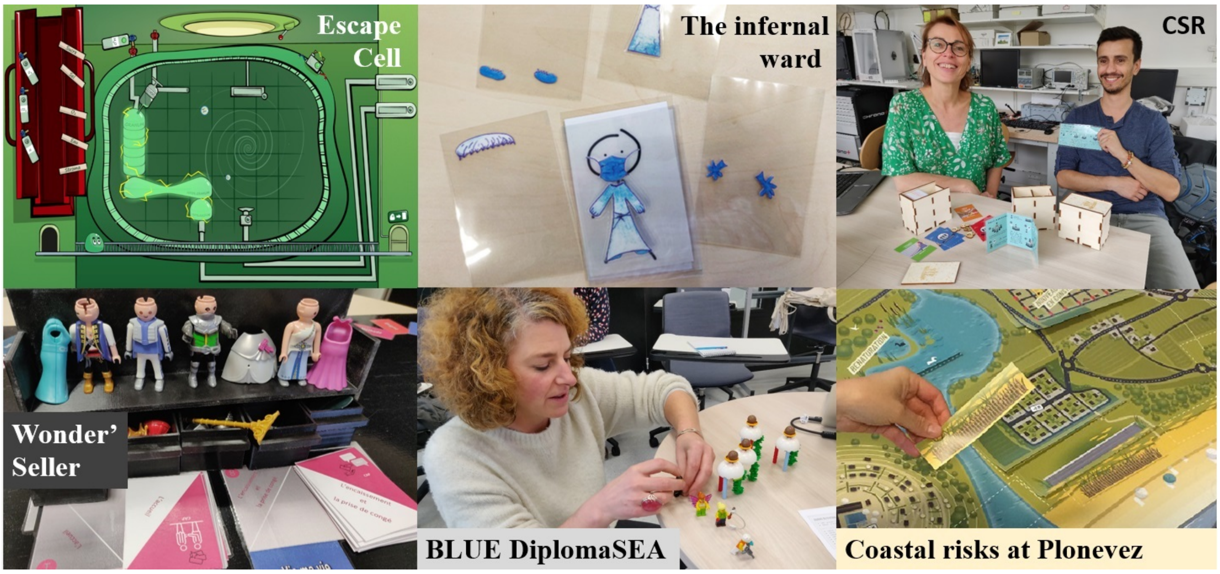


Figure 2.17: Examples of Serious Games designed during Ludifik'action

at the teacher's school (this location has its importance) (*Figure* 2.18). If we look back on the DBR method presented in *section* 3.1.4, this corresponds to one and a half iterations. During the first day, trainees learn the basics of game-based learning theories, practice transforming existing games into SGs and discover as many games as possible. In fact, the course itself is gamified. Ideally, depending on where the training session takes place, they also visit a Fablab. Thanks to a brainstorming session with the trainers, at the end of the first day, the teachers leave with a good idea of what their SG will be like since they have identified the objectives of the future SG, its use and main game mechanics. The teachers must then design a first SG prototype. They benefit from a half-day of personalized follow-up during which one of the trainers comes to their school to test the prototype. The trainer takes on the role of a game designer and helps them find the right game mechanics to improve their SG. The trainer also helps them organize a test session with students if it has not yet been done. After the first test with students, the teachers improve their SG by creating a second prototype. During the last day, all the trainees test their new SGs and share feedback. They are also coached to defend their project when faced with criticism and are encouraged to communicate about their project, as widely as possible. The entire afternoon is dedicated to writing the SG rules, one of the trickiest parts of game design.

Concepts related to game-based learning such as flow, game mechanics and player profiles are distilled into the training session in light touches so as not to overwhelm the trainees. Some of these notions are even presented as "mini bonus information courses" they can "unlock" in exchange for objects they won during the first day of training (funny hats and necklaces). Remember, the training session is itself gamified. The teachers are therefore the ones asking for the information and giving something away to get it, which makes them much more inclined to listen and remember the content. A classic game mechanic! :)

During the entire training session, teachers also have template documents they need to hand in. The list of SG objectives is usually written during the first day of training and the SG description document should be finalize before the follow-up session. At the end of the training session, teachers need to hand in both updated documents as well as the feedback and results of the first tests.

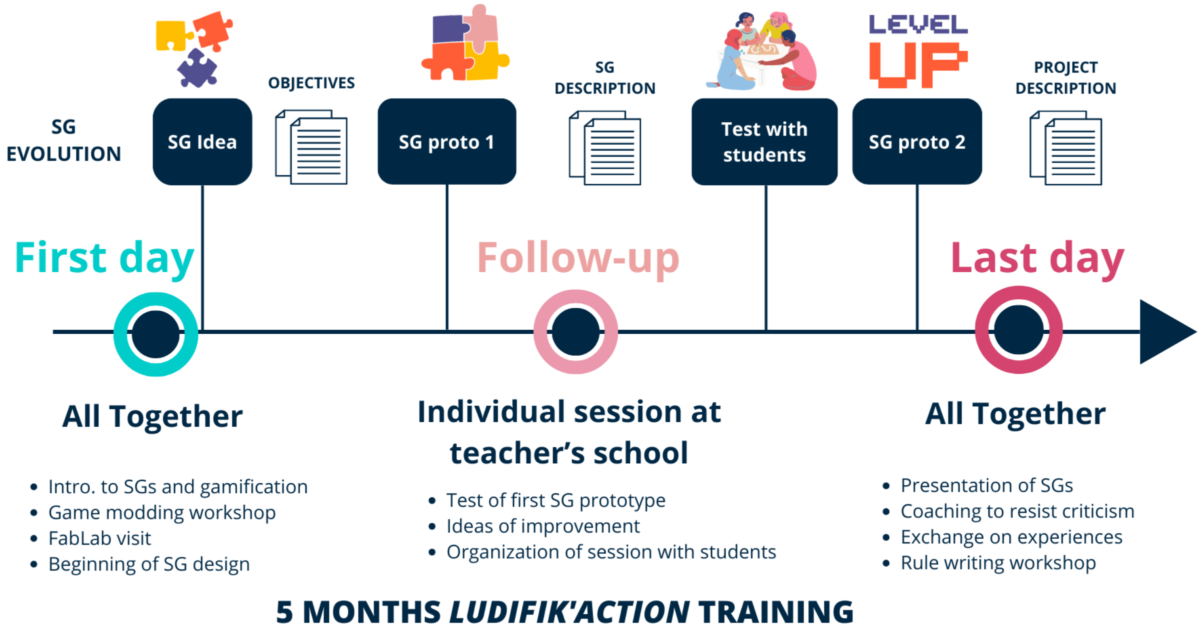


Figure 2.18: Ludifik'action training session

As explained earlier, the merging of universities that led to the creation of Ludifik'action was dismantled a few months later. I therefore had to find other training centers to work with. It turned out that these centers (in different parts of France) had uneven human resources and cost constraints which implied that various organizational changes had to be made in the training session (e.g., duration, follow-up, number of trainees and accompanying staff, presence of a Fablab). These, at first frustrating constraints, turned out to be almost an advantage because they allowed for new configurations. We were able to scientifically compare their effectiveness with questionnaires and comparative statistics on the level of completion of the SG projects (i.e., no prototype, first prototype, testing with students, second prototype and more) (Marfisi-Schottman et al., 2022b).

First of all, we found that teachers who signed up for the training session alone were 33% more likely to not follow through. When teachers are accompanied by at least one colleague, that risk drops to less than 7%. A teacher paired with an educational designer is an ideal team, considering their complementary skill set, but a team of two teachers also works well.

Secondly, we found that the follow-up session was an important element to boost productivity. Groups without follow-up were 50% more likely to abandon. Teachers admitted they had worked hard and slept little the week before our visit to make sure they had a presentable SG. A follow-up session at the teacher's school also seems to be more effective for two reasons: it creates a stronger bond between the trainer and trainee which is important for the constructive criticism they are bound to receive, and the trainer can take into account the physical context in which the SG will be used, and this can influence the game design.

Finally, we found that the more trainers, the better. The brainstorming sessions including larger groups gave teachers a wider range of choices to find a suitable SG scenario. The presence of a Fablab manager among the trainers also seems to increase the effectiveness of the training session. Teachers are more likely to return quickly to the Fablab if they have already met the manager, and this initiates the prototyping phase much earlier. These findings and our observations during the training sessions motivated us to write a series of simple guidelines to help teachers get started on their adventure. These are presented in the next section.

3.3.2 Guidelines to help teachers get started on a Serious Game project

We express the lessons learned from the Ludifik'action training session in the form of 10 commandments for Serious Game Padawans (*Figure* 2.19). A complete version is published in Marfisi-Schottman et al. (2022b).

Figure 2.19: 10 commandments of the Serious Game Padawan

- **1. Think small, you must**. Teachers usually have unattainable goals for their SG. They are unfamiliar with the many professions at play in developing SGs, and unless they have the resources to hire a multidisciplinary team for a year, they are likely to exhaust themselves trying to take on all these roles, and eventually, will be disappointed with the partial result they have achieved. It is therefore important to start with a very small SG project that focuses on one specific part of their course that they want to change (Vanden Abeele et al., 2012). That way, the SG is almost sure to be an effective improvement.

- **2. With other padawans, work you should**. Designing SGs is a long path paved with many obstacles such as redesigning course content, creating game material and communicating about the project to ludo-sceptic colleagues. It is therefore essential for teachers to be surrounded by people who can provide, at the very least, moral support. We encourage each teacher to team up with another teacher or to contact an educational designer, from their school or university, who can provide help.

- **With a master, succeed you shall**. Teachers will have a much higher rate of success in their project if they are accompanied by a professional who can overlook the entire process, provide guidance, encouragement and most importantly, enforce deadlines! We encourage teachers to seek out professional training, such as Ludifik'action, or university diplomas with a professional follow-up over several months.
- **In other games, inspiration you will find**. Commercial games are the product of years of development iterations, tests and improvements. It is therefore in the teacher's best interest to draw inspiration from existing games (or parts of them) (Abbott, 2019), (Stanescu et al., 2016). Our experience in Ludifik'action shows that simple games such as *Time Line, Taggle, Concept, Who am I*, or even children's versions of games are particularly of interest because they have very simple rules and can be complexified with educational content.
- **Like you, the game must be**. When a SG is intended to be used in class, teachers play a central role in facilitating the game (explicitly, if they are game masters or implicitly, if they are not). The teacher's positive and engaging attitude is therefore essential for the SG to run smoothly. Consequently, teachers need to design a game that they are comfortable with (Sanchez et al., 2015).
- **Exploit your students, you can**. It is useful to involve learners, from the beginning of the design process, in the choice of game mechanics and game world to make sure it appeals to them (El-Nasr and Smith, 2006). They can also be asked to create parts of the SG during a project. Several studies show the positive educational effects of asking learners to design their own SGs (Švábenský et al., 2018), (Arnab et al., 2015).
- **Justify the game mechanics, you must**. Many SG design methods are proposed by researchers (Arnab et al., 2015), (Kelle et al., 2011), but none of them has full consensus in the community. The general rule, found in all methods, is that the choice of each game mechanic should be justified according to the pedagogical objectives (Graesser, 2017). Our experience shows that it is important that teachers take the time to justify the choice of game mechanics themselves, in writing, to help them build a solid argumentation and defend their project.
- **Introduce and debrief after the game, necessary it is**. The majority of teachers think that SGs are sufficient on their own, but this is not necessarily the case. Teachers must explain why they have chosen this unusual form of pedagogy and list the skills that will be used. If the SG involves an immersive imaginary world and game scenario, a debriefing phase is necessary after the game to recall the concepts and skills that have been used and to discuss how they can be applied in other contexts (Lederman, 1992).
- **Crucial, the design is**. The pleasure of play depends greatly on the graphics and the ergonomics of the game material (Marne and Labat, 2012). We encourage teachers to get in touch with a Fablab, use box and card templates and purchase game material (e.g., pawns, dice, tokens) from specialized sites. A well-proportioned box, with compartments, is particularly important as it is the first contact with the SG and will encourage learners to put the material away correctly at the end of the game.
- **Play, you will**. Most teachers only remember a few classic games they played as children (that sometimes left them with bad memories) such as *Monopoly, Scrabble* or *Trivial Pursuit*. Yet, thousands of new games are created every year, including collaborative games

that are much more suitable for classroom use. The best way to understand the tensions, interactions, dilemmas and emotions triggered by a specific game mechanic is simply to try it out in a game. It is therefore essential for teachers to play.

3.3.3 Discussion and positioning of the work

SG design is a main research topic in the field of SGs. Countless methods and models have been proposed, but none of them are totally satisfactory and therefore none have been given full consensus by the community.

There are three main types of SG design methods and models. The first type claims to work for any type of SG, educational content and context of use. This is the type I proposed during my PhD. They usually offer a method that identifies what and when the various actors (game designer, teachers) should do in addition to a complex model that represent the intertwined educational AND game scenario. The second type of SG design methods are focused on one type of SG such as educational escape games (Guigon et al., 2018) or collaborative educational games (Guigon et al., 2023). The third type focuses on modifying existing games. This is called "game modding" and basically consists in changing the content of a game while keeping the game mechanics and sometimes even the game material (El-Nasr and Smith, 2006), (Abbott, 2019).

In reality, none of these completely meets the needs of teachers. The first one is way too complicated and usually involve actors, such as game designers, that teachers simply do not have access to. The second and third type are much easier to use but they are restricted to one specific type of game. It is very unlikely that teachers will stumble upon the right one for their pedagogical needs and, even if they do, the models are so rigid that there is very little place for trying out new game mechanics that could be much better for their content or simply adding a personal touch, essential to help teachers really imagine themselves using it.

Our approach actually combines these three types of SG design methods. The trainers (colleagues and myself specialized in SG design) play the role of game designers, acting as middle-men between the teachers and other actors (i.e., Fablab managers, graphics designers, developers) or between teacher peers who have carried out similar projects. The first day, teachers perform several game modding sessions to help them understand that is it easy to do, but we always encourage them to think outside the box to find new game mechanics that could be better suited to their needs. Finally, after the teachers have decided on the outline of their SG, we provide them with specific tools and models that fit the type of game design they have selected (e.g., SG escape game models, tools to create branched storylines, tools to create geo-located treasure hunts).

One of the most interesting discoveries that we made during this project was the fact that creating SGs made some teachers "fall in love with teaching again". It changed their frame of mind as a teacher and gave them more confidence and motivation in their work. And this is regardless of the quality of the SG produced. The teachers were equally ecstatic, whether they produced amazing SGs or mediocre trivial pursuits (even though we had firmly warned them against it). The point is, even if they created a SG that we did not consider fantastic, it was THEIR SG, they were happy and proud to use it and that just makes a huge difference.

Out of the 26 teachers who produced a SG prototype during the training session, nine continued to improved their SGs or created other SGs Several also helped colleagues create their own SG and when on selling their SG as learning material. Knowing that teachers have very busy agendas, the fact that 35% pursued beyond the training session is very impressive! Two teachers were also interested in writing research papers about their SGs and the impact it had on the way they teach. I therefore wrote several scientific publications with Cindy FURNON (teacher) and Thomas LONGEON (educational designer), who participated in the 2020 edition of Ludifik'action (Furnon et al., 2022), (Longeon et al., 2023). These papers present their game *Wonder'Seller* but also the way it can be integrated into the curriculum by varying the rules. We also wrote a paper with a group of educational designers who help a biology teacher create several game modules for her first year class on plant cellular biology (Liu et al., 2023). These modules have been integrated into the university's e-learning system. A statistical comparative analysis shows that the use of a SG significantly increased the grades of students, by almost two points out of 20. Even though the game was not strictly mandatory, 88 out of 117 students played it. We also found evidence of the usefulness of some of the game mechanics such as a non-player character named Blob and hidden bonus information modules.

The Ludifik'action training session has been quite successful. It won a national PEPS (*Passion Enseignement* et *Pédagogie dans le Supérieur*) prize in 2018 and our article on the 10 commandments of the SG padawan, briefly presented above, won the best paper award of the 2022 Games and Learning Alliance Conference in Tampere, Finland. I have also presented several keynotes on the subject at conferences organized by Universities or schools to encourage teachers to create SGs. The 10 commandments are also available as a video capsule for an online course on pedagogy in higher education. The training session is now being duplicated in other universities such as Paris (2022), Nice (2023) and Le Mans (2023), with other trainers. We are working on an article that explains the method, from the trainer's point of view, and have given access to the source documents to further promote Ludifik'action.

3.4 Conclusions

In this chapter, we present several of our contributions to advance scientific understanding of how game mechanics, ML and HCI can be used for education. We have carried out several research projects to design innovative TEL systems with teachers and have tested them in their classes to define design principles. However, these types of projects are costly, time consuming and sometime yield mediocre results. We therefore propose a pragmatic method to conduct these research projects to maximize productivity based on our experience of using the Design-Based Research method for seven projects. It is intended to help researchers, teachers and theirs learners work together. This is complementary to the seven facets of collaboration between researchers in social sciences and computer science proposed in the first chapter.

Research is largely build on previous experience. However, a large majority of SGs are designed by private companies and are therefore not present in the scientific literature. For this reason, we also propose a catalogue, a metadata schema and models to help teachers, but also researches, find existing SGs and share their own. This is a good start but such a system needs to be carried by a large community of teachers to have an impact. Yet, we believe this path should be pursued because there is a strong demand from teachers but also from universities to regroup all types of pedagogical innovations in a catalogue. To be truly useful, this catalogue needs to include the finished products (e.g., applications, SGs, non-digital SGs) but also the design material, which will enable teachers to reuse and share their Open Educational Resources (OER).

Finally, we propose a training method and guidelines to help teachers create their own SGs or TEL systems with the available resources. We have obtained very positive results, not so much regarding the quality of the SGs produced, but rather the motivation and drive these SGs gave to their teacher/designers. The next chapter aims to pursue this objective by providing teachers with simple TEL authoring tools that integrate the design principles found in research, but that also give them a lot of creative leeway so they can create their own content and make the tools their own.

TAKE AWAY MESSAGE

This second chapter reports on our efforts to achieve our first researcher objective, RO 1: provide methods, models and tools to help all necessary actors design effective TEL.

We first propose **several design principles for using technology** for various educational objectives and in various contexts:

- TurtleTable(t): using collaborative game mechanics and tangible objects to teach middle school children the basics of computer programming
- SMART-Fractions: using game mechanics and Mixed Reality to teach children how to understand the notion of fractions on a number line.
- TGRIS: using a Virtual Reality simulator to help professionals deal with their emotions in complicated situations.

We also propose an **automatically-updating catalogue** (*JEN-Planet*) to help teachers and researchers find existing SGs.

Finally, based on our experience, we propose:

- A pragmatic implementation of the Design-Based Method with gradual implication of researchers and teachers.
- Guidelines and a training method to help teachers create their own original educational tools such as SGs (digital and non-digital) with the available material resources and staff.

3.5 Related publications

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pp.307-318.

Vinatier I., Marfisi-Schottman I., L'irruption des émotions entre conseillers pédagogiques et enseignants débutants : quelle conception de formation pour les mettre à distance ? L'analyse des interactions dans le travail, Vinatier I., Filiettaz L. et Laforest M., Raison et Passions, 2018, 26p.

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CHAPTER 3

Adaptable Models and Authoring tools

Enabling teachers to create technology-enhanced learning systems themselve

Chapter 3

Adaptable Models and Authoring Tools

Enabling Teachers to Create Technology-Enhanced Learning Systems Themselves

Contents

1 Introduction

This chapter focuses on the second research objective, which is to **provide adaptable models and authoring tools** to facilitate TEL development and thus increase their acceptability and use (*Figure* 3.1). This research objective addresses research challenges from our three main research branches. The challenge for Serious Games (SGs) is the very high production cost to hire an entire team of game designers, developers and graphic designers (C3[SG]). For innovative Human-Computer Interactions (CHI), the development is complex because it requires developers who are specialized in the chosen technology (e.g., Virtual Reality, Mixed Reality) (C2[CHI]). Acceptability and use is a challenge for pretty much all innovative TEL systems. SGs, ML and HCI are seldom used in schools, for professional training or even for educational tourism, even though they offer numerous advantages (C4[SG] C3[ML] C3[CHI]). Finally, the integration of ML is complicated because mobile devices are usually not allowed in schools (C2[ML]).

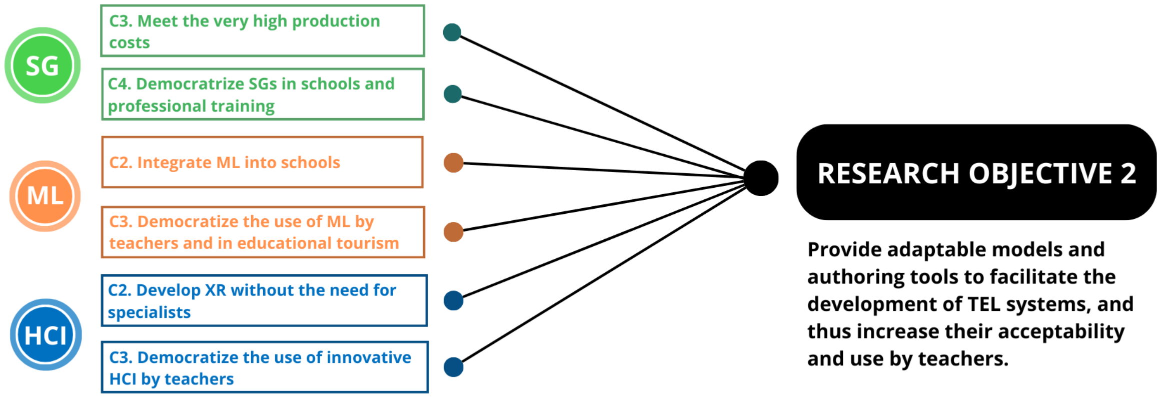

Figure 3.1: Second research objective

As explained in the introductory chapter, **authoring tools** are a promising solution to all these challenges. They offer two main advantages (*Figure* 3.2):

- **Authoring tools cover a large variety of teachers' needs**: Unlike usual TEL systems that are built for specific learning objectives, learner profiles and context of use, such as those presented in the last chapter, authoring tools cover a much larger variety of needs and can therefore be potentially used by a large number of teachers. Even though their design is quite complex, as we will explain later, the return on investment can therefore be much higher than that of classic TEL projects.

- **Authoring tools can encourage collaborative TEL systems design**: If the authoring tool offers collaboration functionalities or simply the possibility of copying another author's content, it gives teachers the possibility of collaboratively designing TEL systems. Communities of practice can evolve to help teachers get started with the tools and make the most out of its functionalities. The existence of such a community is an important factor in the decision to adopt a TEL system in the classroom (Rodríguez-Triana et al., 2020) and it constitutes a good way to encourage more teachers to use a system and improve the authoring tool.

These advantages encourage a wider use of authoring tools, which research directly benefits from, as it can feed on the experience of many alternative versions of TEL systems or instructional strategies that are created and tested with a large number of participants. This virtuous circle is essential in identifying new design principles and finding hard evidence of the effectiveness of TEL (Murray, 1999).

In addition to the advantages of the authoring tools themselves, the TEL systems they produce also have three major advantages for teachers:

- **Authoring tools produce "ownable" TEL systems**: They allow teachers to create custom content which gives them a sense of ownership. It is their production, they have spent time creating the content, they know how it works and will therefore feel comfortable using it in the classroom. As we highlighted in the last chapter, this sense of ownership has a positive impact on the teacher's attitude, their motivation to use the TEL system and its chances of being accepted in the long term. They become active agents which fosters a change in the learning paradigm (Mumtaz, 2000).

- **Authoring tools produce adaptable TEL systems**: Teachers can change the content whenever they want because the content is not hardwired into the code. This is a huge advantage because the system can be improved, adapted to new content or new students and reused, year after year.

- **Authoring tools produce low-cost TEL systems**: The third advantage is that these tools can reduce development time, effort and cost because they do not require the intervention of specialized developers or graphic designers (Murray et al., 2003). This is much more in line with the reality of teachers. They simply do not have the resources. Some teachers pay for their own computer, printer paper and scotch tape, even though these are basic work tools.

However, there is a catch.... It would be too easy otherwise. TEL authoring tools present us with two main design challenges (*Figure* 3.2):

- **Balancing power and usability**: Authoring tools need to be based on highly adaptable models that meet the needs of as many teachers as possible, while remaining as simple as possible. This balance is described by Murray (2004) as the product of design tradeoffs between power/flexibility and usability. It is extremely difficult to achieve because authoring tools need to be simple and easy to use, yet allow teachers to create a wide variety of educational activities and scenarios. Those who design authoring tools must therefore make hard choices on what features to include in the tool, based on the most common teachers' needs. Similarly, teachers should be able to create their activities very quickly, by providing minimal information, even though the authoring tool needs a large amount of precise information to generate the code. This entails the use of simple template models with predefined values and complex implementation models (hidden from teachers) capable of transforming the template models into low-level code blocks. The design of such models is usually only possible in fields of TEL that have reached a certain maturity and have a set of well-proven design principles.

- **Helping teachers discover new ways of teaching**: In order to use authoring tools, teachers need to re-conceptualize their course content to fit the given model (Murray, 2004). But it is not enough to put existing educational content into the authoring tool. Or rather, we should say it is a shame not to think outside of the box. Indeed, we agree with Dias and Atkinson (2001) that authoring tools should ideally have a positive influence on teachers by providing them, for example, with the means to create original learning content that requires technology or game mechanics that they were previously unfamiliar with. This is the point of conducting experimental research such as that described in the previous chapter: to find new pedagogical design principles from which teachers can benefit. However, researchers have found that most TEL systems are used by teachers simply to replicate the same learning paradigm (Coomey and Stephenson, 2001), (Sheffield, 2011). For example, teachers mostly use e-learning platforms as a file repository! At our university, out of 974 teachers, only 2.36% use Moodle's interactive and gamification features, 2.15% use modules that encourage reflection, such as surveys and auto-graded MCQs and only 1.54% use features that encourage collaboration, such as peer evaluation or wikis (Bennacer, 2022). Authoring tools therefore need to provide guides to help teachers make the most of the available functionalities. The UX (User eXperience) design is also very important to help increase the perceived affordance of authoring tools (Bower, 2008). The aim is to encourage teachers to try out new features and use the authoring tool to its full potential. In short, teachers need scaffolding to help them rethink their content.

A final challenge is the acceptance of authoring tools. As teachers spend a lot of time using them to create their content, the robustness and the longevity of such tools is paramount. Teachers will be reluctant to spend time learning how to use a new application if they are not sure it will not crash or that the service will simply be discontinued. We will not talk about this is this chapter because it will be covered in the next.

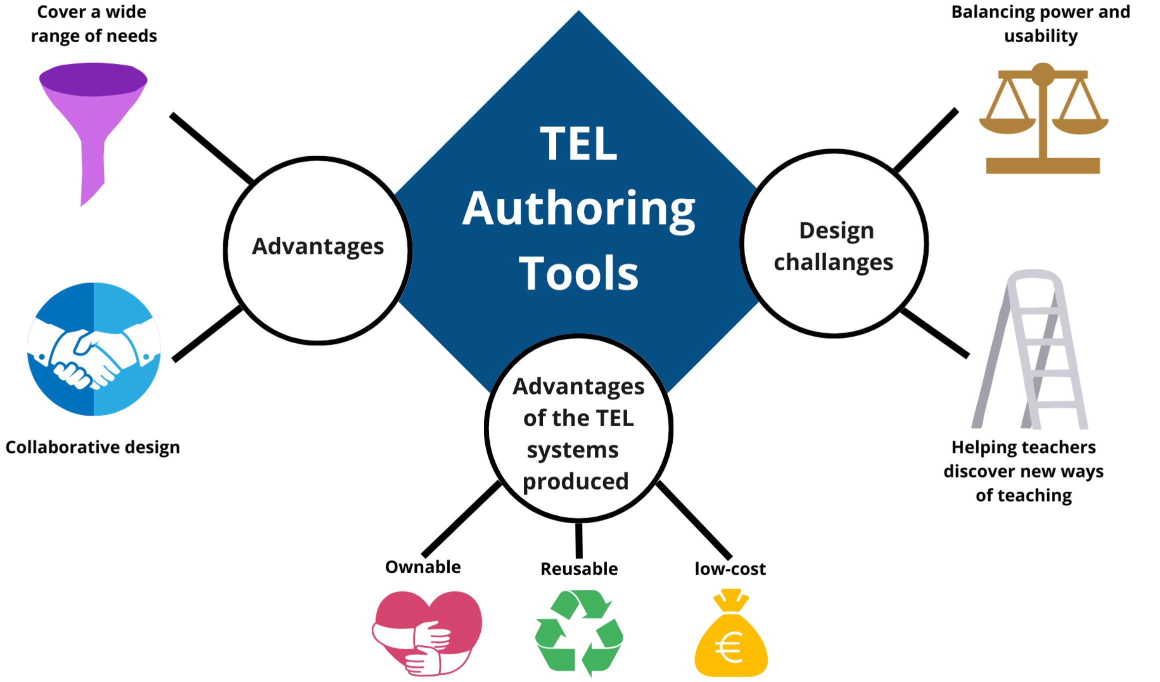

Figure 3.2: Advantages and design challenges of TEL authoring tools

In this chapter, we present the directions we have taken to address these design challenges for two specific types of TEL systems. The first type is **Mixed Reality (MR) educational activities**. The project we conducted with 20 pilot teachers allowed us to come up with original ways of using MR for learning. We also propose a very simple workflow for the authoring tool that allows teachers to create their activities in three to five steps. The second type of TEL system is **Mobile Learning (ML) applications for educational field trips**. The proposed model for this type of TEL covers a wide variety of outings such as treasure hunts, geocaching, orienteering races, museums visits or sightseeing. The last direction we have taken is to **propose guidelines (based on our experience above) for conducting research on authoring tools**.

2 Research context and questions

2.1 What models and authoring tools can enable teachers to use Mixed Reality?

Mixed Reality (MR) has been shown to have several advantages for formal and non-formal learning (Dengel et al., 2022). Because MR creates a multimodal playground for presenting and interacting with content in an immersive way (Roopa et al., 2021), learners can better interact and enact concepts through sound, sight, motion and haptics (Xiao et al., 2020). Such immersive modalities can support multisensory and experiential learning (Shams and Seitz, 2008) in many disciplines, including art, design, science, technology, engineering, mathematics and medicine (Ibáñez and Delgado-Kloos, 2018). Research clearly argues that schools should integrate MR into their curricula to enable immersive learning that engages learners and facilitates understanding of content and phenomena (Billinghurst and Duenser, 2012). In France, the use of Augmented Reality (AR), which is one type of MR, is even officially recommended by the Ministry of Education. In July 2022, a post on the national Eduscol portal proclaimed that AR is a particularly suitable technology for use in schools, as it empowers students, links the digital world to the real world and enhances learning through information spacialization (Eduscol, 2022).

However, like the *Magic Cauldron* presented in the last chapter, **most MR applications are designed to meet a specific educational need** (e.g., learning fractions on a number line for children from 9 to 12 years old). Other MR applications offer impressive 3D models of the human body or natural phenomena such as a volcanic eruption or the rotation of the planets in the solar system. Although these applications clearly create an initial "wow effect", teachers find it difficult to really integrate these tools into their course because the content is not perfectly adapted to their needs (too complicated or too simple and 90% of the time in English, which is a real problem for French teachers).

In addition, **authoring MR experiences requires considerable technical knowledge and skills** (Nebeling and Speicher, 2018). The vast majority of AR and MR applications are created using advanced programming and complex toolkits such as Unity3d, Unreal Engine, Vuforia, ARCore or Three.js, which require highly skilled and specialized developers. There is therefore a clear need for authoring tools that enable teachers to create their own content.

In fact, an impressive number of authoring tools already exist, but they are not being used by educators. In a recent state-of-the-art study, we analyzed 21 educational authoring tools from academia and industry to identify their authoring workflows, the types of MR educational activities that can be created with them and other functionalities. In parallel, we organized co-design sessions with 19 teachers to identify their real needs in relation to these four dimensions. The result of this study is clear: **existing authoring tools do not meet the real needs of teachers** (Ez-Zaouia et al., 2022). For example, 16 out of 21 tools require an Internet connection on the tablets, which is a deal-breaker in France because most schools simply do not have WIFI. Basically, the authoring tools that offer rich activity models and many functionalities are much too complex and require several hours of teacher training. This is the case with *MirageXR* (Masneri et al., 2020). And the authoring tools that are easy to use offer very limited activity models and functionalities. In this category we have *ARTutor* (Terzopoulos et al., 2021). Typically, this last type of authoring tool only allows the user to superimpose an AR image on top of another image (e.g. from a book or poster), which is quite limiting in terms of pedagogical potential. This is a clear illustration of the design trade-offs between power and usability explained in the introduction to this chapter.

We therefore have two research questions:
- RQ8. What adaptable models can be used to design educational Mixed Reality activities?
- RQ9. What authoring tool can enable teachers to create Mixed Reality applications for educational purposes?

We use a bottom-up approach to address these issues. In the MIXAP project, we selected a representative group of pilot teachers, working from pre-school to the university level, to make sure we had a wide variety of educational domains. We asked them to create paper prototypes of the MR educational activities they would like to create for their class. We then analyzed their prototypes to find invariable activity models on which we built the *MIXAP* authoring tool. The interface, vocabulary and user guide for *MIXAP* were also designed with the pilot teachers.

2.2 What models and authoring tools can enable teachers to create Mobile Learning applications?

The situation for Mobile Learning (ML) is very similar to that for MR presented above and we have published several articles on the subject, so I will summarize it.

ML offers many advantages for teaching, especially for creating fun, geo-located mobile applications for educational field trips (e.g., visiting a museum, discovering a city, orienteering races) (Karoui et al., 2016), (Marfisi-Schottman and George, 2014). However, their design is technically complex and it is difficult for teachers to share scenarios, as the scenario is highly dependent on the location where the outing takes place. Therefore, there is a need for authoring tools.

Although authoring tools for ML exist, they are either too complicated (but powerful) **or very limited in terms of functionality** (but easy to use) (Karoui et al., 2016). In addition, all the authoring tools that offer geo-located activities require an internet connection, which is not compatible with the use of school tablet that are not set up with mobile phone plans to provide a data connection.

We therefore have two research questions:
- RQ10. What adaptable mobile learning game model can be used for educational field trips?
- RQ11. What authoring tool can enable teachers to create their own mobile applications for their field trips?

We have been working on these questions for almost 10 years. Working on three successive ML projects (JEM-Inventor, ReVeRIES and SituLearn) has given us the opportunity to perfect the models and authoring tools. As the field of ML is much more mature than MR, we were able to build on existing situated ML models and improve them with the help of pilot teachers. During these projects we also experimented with different authoring strategies. We focused on setting up scaffolding tools to help teachers use the authoring tools not only to recreate their current field trips, but to go beyond and incorporate new game mechanics and activities. In the last project, we also provided teachers with tools for the class debriefing session after the field trip. Such tools are often overlooked in similar research projects.

2.3 What design methods are used to create authoring tools?

By now, you are probably convinced that authoring tools are a very promising direction for TEL, not only for research (because they allow different learning strategies to be created and tested), but also for the use and acceptance of TEL systems in schools. However, to our knowledge, there is no clear design methodology for creating these authoring tools. Murray et al. (2003) insist that teachers need to be involved in the process, but there are no other specific recommendations. Of course, we can use the Design-Based Research (DBR) method presented in the previous chapter, which works for all types of TEL, but authoring tools have specificities that should be taken into account. For example, how should the pilot teachers be recruited to ensure that the authoring tools will meet the needs of as many teachers as possible? How do you decide on what to include in the generic model and what is too specific and should not be included because it would only complicate the authoring tool?

We therefore have two additional research questions:
- RQ12. What are the design principles for TEL authoring tools?
- RQ13. What guidelines can facilitate the management of authoring tool project?

We try to answer these questions based on our experience with the four authoring tools projects mentioned above: MIXAP, JEM-Inventor, ReVeRIES and SituLearn. This is presented at the end of the following contributions section.

3 Contributions

3.1 Models and authoring tools for educational Mixed Reality

The research presented in this section addresses the following two questions:
- RQ8. What adaptable models can be used to design educational Mixed Reality activities?
- RQ9. What authoring tool can enable teachers to create Mixed Reality applications for educational purposes?

The work presented in this section was carried out as part of the ongoing MIXAP project led in collaboration with 20 pilot teachers and Canopé, the national teacher training network. The aim of the project is to provide a simple authoring tool that can be used by teachers, from pre-school to university, to create their own educational MR applications using the equipment that they already have in their classroom. As shown in *Figure* 3.5, the teacher can use the school tablets or their computer to create the MR activities, and then the students can complete these activities using the school tablets or their smartphones.

To illustrate how our pilot teachers have used our authoring tools and the variety of educational activities they have created with them, we have included two testimonials in this chapter (*Figure* 3.3 and *Figure* 3.4). The others can be found in the appendix.

In this section, we will first present the MR pedagogical activity models designed with the pilot teachers. Then we will present the interface and main functionalities of the *MIXAP* authoring tool, which was built based on these models. Finally, we will present the first results

Figure 3.3: Testimony of a pre-school teacher who used MIXAP

Figure 3.4: Testimony of a high-school teacher who used MIXAP

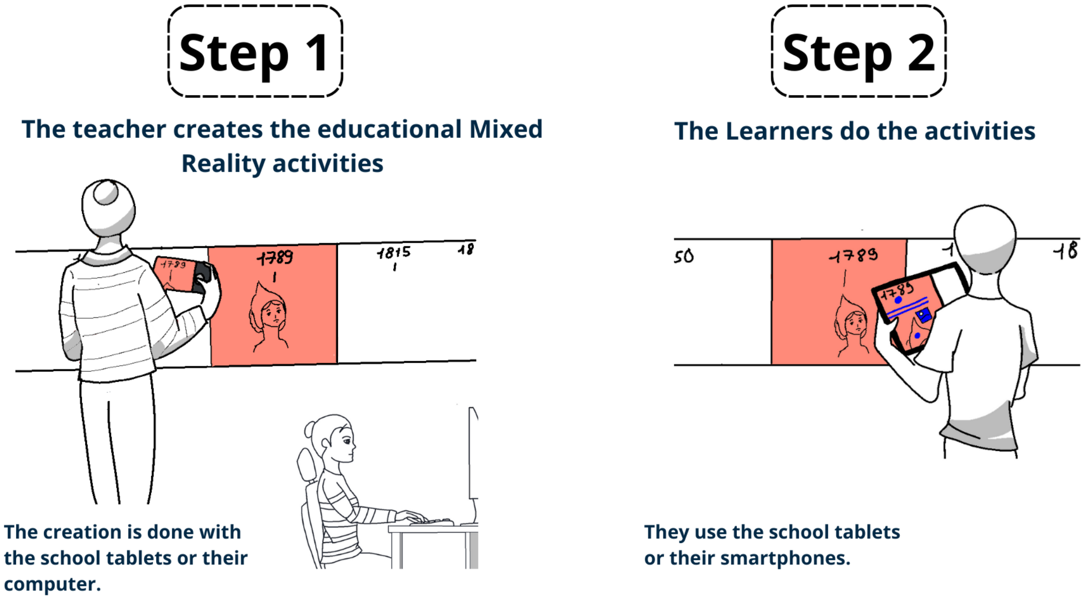

Figure 3.5: Steps for using the MIXAP authoring tool

of the experiments carried out in schools.

3.1.1 Mixed Reality educational activity models

As shown in *Figure* 3.6, *MIXAP* offers four types of MR pedagogical activities and two ways of organizing them. These were defined thanks to the design sessions that we held with the 20 pilot teachers (11 local teachers from Pays de la Loire and 9 from Futuna, an island in the middle of the Pacific). During these design sessions, the pilot teachers were asked to imagine the activities they wanted to design for their class and to formalize them with a paper prototype (Ez-Zaouia et al., 2023). The method used for this co-design session is presented at the end of this chapter, in the guidelines for designing authoring tools.

The analysis of these paper prototypes shows that the type of activity most needed by the pilot teachers is **image augmentation**. This activity allows multimodal resources (text, image, video, audio, 3D model and supplementary information sheets) to appear on an image marker (e.g., poster, book, exercise sheet). For example, a primary school teacher wanted to add pictures of animals and audio recordings of important vocabulary (e.g., "a reindeer has four hooves and two antlers") to the pages of a book. Another high school teacher wanted to display 3D models created by his students in the class yearbook. The analysis of the co-design sessions also revealed other, more original types of activities, such as **image validation**. This allows for the creation of autonomous activities in which MR automatically validates whether the chosen image is correct. For example, a high school technology teacher wanted students to identify a specific part of a machine (e.g., the engine). The third type of activity identified was **associating two images**. This technique also allows teachers to create autonomous activities as it provides feedback so that students know if they have correctly matched two associated images. For example, one pre-school

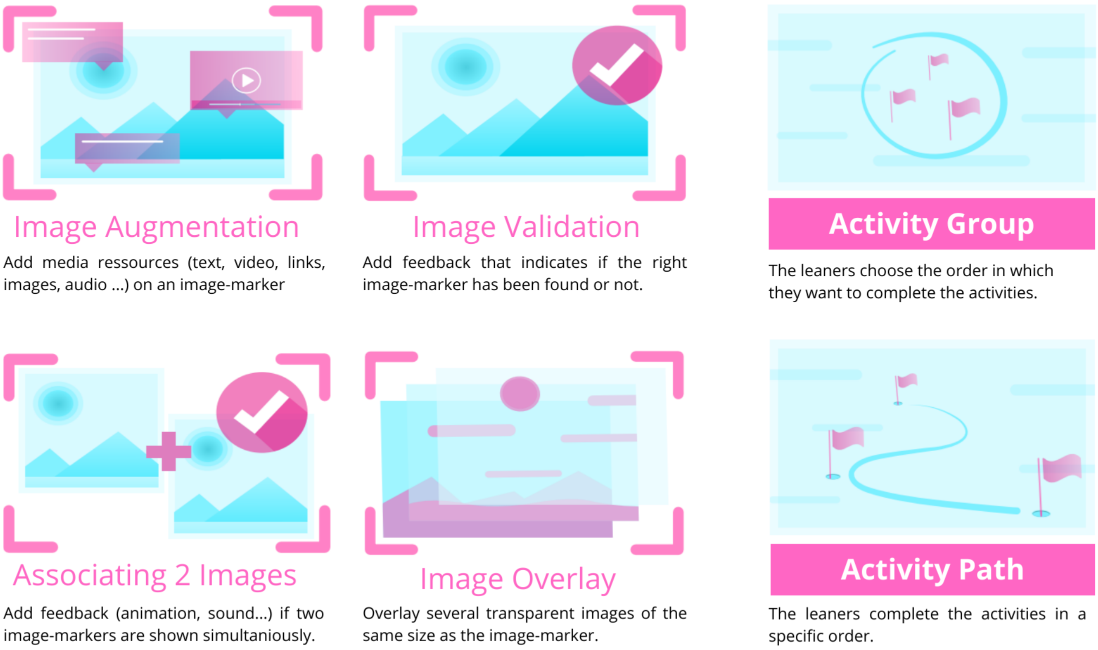

Figure 3.6: Types of educational MR activities offered by MIXAP

teacher said that she wanted the children to practice recognizing the same letter written in upper and lower case. Finally, the last type of activity is **image overlay**, which allows students to see transparent layers on top of an image. For example, a university geology professor wanted students to be able to turn on and off layers showing different types of rock on a picture of a mountain. Other teachers wanted to use this type of activity to show the answer to an exercise. Finally, the analysis of the paper prototypes showed that teachers wanted to combine the different activities presented above either into a group of **activities**, without a predefined order, or into an ordered **activity path**.

3.1.2 Educational Mixed Reality authoring tool

The *MIXAP* authoring tool can be used both by teachers, to create the four MR activities described above as well as by students to carry out their activities. It is a web application that can be used on different devices such as computers, tablets and smartphones. It is designed to work locally (progressive web app) and therefore does not require an internet connection, except for the initial connection to the application and when sharing activities from one device to another.

MIXAP provides a simple design workflow with steps to create an activity using visual and intuitive interactions. *Figure* 3.7 shows the four steps for creating an image augmentation activity: naming the activity, taking a picture of the image marker, adding the augmentations and testing the activity. Once activities are created, teachers can share them with their students in read-only mode. Teachers can also share in editor mode so that other teachers can reuse and modify their activities.

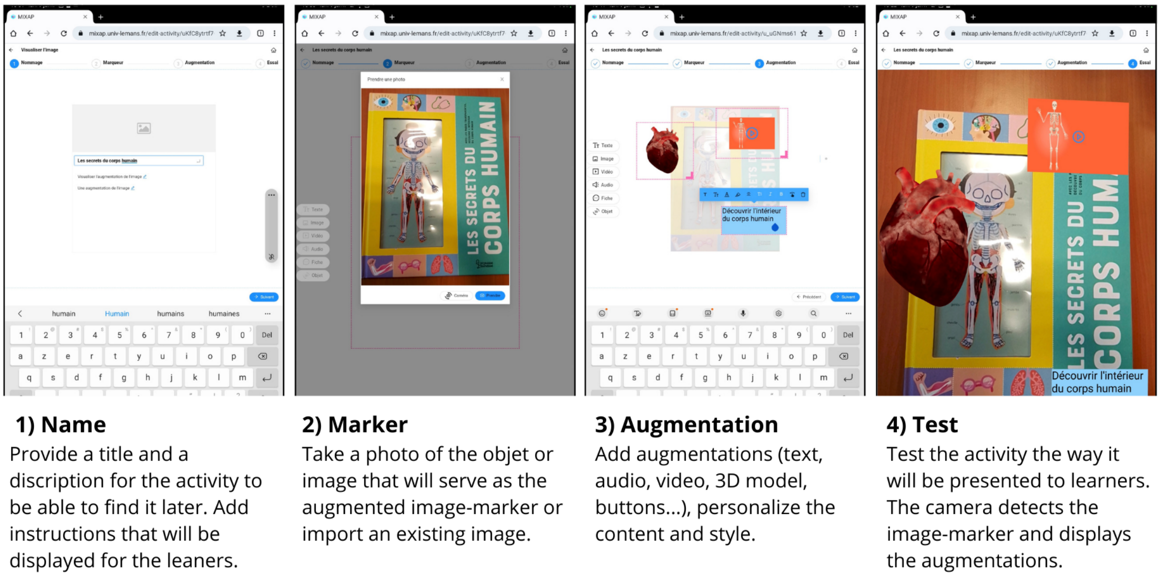

Figure 3.7: Simple four-step workflow offered by MIXAP

3.1.3 Experiments with teachers

Several experiments were conducted on the first and second *MIXAP* prototypes. The first experiment focused on the authoring tool's usability (Is it easy to use?), utility (Is it useful?) and acceptability (Will it be accepted by teachers?). We asked pilot teachers and teachers who were discovering *MIXAP* for the first time, to create several activities and then fill out questionnaires. The results were very encouraging (Ez-Zaouia et al., 2023). In terms of **usability**, the average score for all the 39 participants was 73.91, which is above the standard SUS average of 68 points and is classified as "good". **Acceptability**, especially in terms of low cognitive load, is also very good (average of 1.5 out of 5). In addition, we found no statistically significant differences between pilot and non-pilot teachers ($p = 0.180$), nor according to teachers' profiles ($p = 0.889$ for the age and $p = 0.520$ for the teaching discipline). This means that *MIXAP* is very easy to use for all teachers, including those who have just discovered it. The only statistically significant difference was related to the perceived **utility** ($p = 0.043$): while the pilot teaches gave a high score (average of 4 out of 5), the others gave a score under the median (average of 2.5 out of 5), meaning that they did not see how *MIXAP* could really be useful for their courses. We intend to improve this during the next year of the project by providing more tutorials and examples of how *MIXAP* can be used, inspired by what the pilot teachers have done.

The second experiment focused on the impact of *MIXAP* in students and teachers. Ten experiments were conducted in the classrooms of the local pilot teachers. This was organized in three phases. In the first phase, we observed the pilot teacher creating the MR activities without any help. We noticed that the teacher's initial project (written on the paper prototype) often evolved into something more complex and rich, where the technology was only a small part of the activity. After testing *MIXAP*, two teachers found the tool so easy to use that they decided to ask the students to create the activities (in middle school and technical high school). In the

Figure 3.8: First session of the MIXAP experiments in the classroom

second phase, we observed how teachers and students used *MIXAP* in class (*Figure* 3.8, left). We noticed many interesting phenomena. For example, young children found it hard to hold the tablets still and click on the augmentations at the same time. This forced them to develop collaborative strategies, which were encouraged by the teachers. One of the teachers also used *MIXAP* to animate the portrait of Alfred WEGENER on the exercise sheet to make it look like he was reading the description of the exercises to the students. The last phase was a semi-directed interview with the teachers to get their feedback on the use of *MIXAP* and to understand if it met their expectations in terms of pedagogical benefits (*Figure* 3.8, right). The sessions, which are still being analyzed, were very interesting. For example, the teachers noticed that several students who usually have trouble concentrating or did not speak French were very well integrated into the group. In fact, these children were so well integrated that we did not even realize they had any particular difficulties! We even suspected that the teachers had deliberately selected a group of very bright and well-behaved students for the experiment. The first results are reported in (Mercier et al., 2023) and several other articles are in the writing or evaluation stage.

3.1.4 Discussion and positioning of the work

MR is still a very new technology in TEL and its potential for education has yet to been fully discovered. Interestingly, probably because of the marketing value of the "wow" effect it provides, most educational MR applications are being developed by private companies rather than by researchers. This has resulted in a large number of impressive-looking applications being created with very little thought given to their impact on learning. However, several major research projects are underway and should soon improve our understanding of how to use MR to its full educational potential.

As you may have noticed, our approach is again teacher-centered. Teachers provide the inspirational material from which we build the educational MR models. We believe this approach is very effective because the teachers see the technology from a different angle and find new ways to use it. For example, in this project, they have found three new ways to use MR for educational purposes (image validation, associating two images, and image overlay), even though, from a computer scientist perspective, they all use the same basic functionality of image recognition.

The MIXAP project is very young (started in January 2022) and modest (126 k€ funding), but the first results, especially in terms of usability and the variety of educational activities created by the pilot teachers, have clearly exceeded our expectations.

3.2 Models and authoring tools to create Mobile Applications for field trips

The research presented in this section addresses the following questions:
- RQ10. What adaptable mobile learning game model can be used for educational field trips?
- RQ11. What authoring tool can teachers use to create their own mobile applications for their field trips?

As mentioned in the first part of this chapter, the work presented in this section has been carried out in three consecutive projects over almost 10 years.

The first project, called **JEM-Inventor**, was part of my installation project at LIUM in 2013. The goal was to enable teachers to create their own geo-located smartphone applications for their field trips and deploy them on available devices (school tablets or the students' smartphones). The idea was to provide teachers with an authoring tool and a set of activity models to take advantage of the positive interdependencies between collaboration, gaming, mobility, and learning (Marfisi-Schottman and George, 2014). Thus, the goal is to use the game mechanics and functionalities offered by modern smartphones and tablets to enhance situated learning. Thanks to the study led by my first Ph.D. student, Aous KAROUI, we proposed a geo-located activity model and developed the authoring tool *JEM-Inventor*. It offered an original nested design approach to help teachers gradually discover functionalities according to their profile and needs. This project was carried out in collaboration with seven pilot teachers.

The same model of geo-located activity was then perfected in the **ReVeRIES** ANR project, which focused on learning about plants and which involved three pilot teachers in botany. For this project, we developed another authoring tool, called *MOGGLE*, in order to experiment with the functionalities related to the collaborative design of field trips, which was one of the focuses of the project (Gicquel et al., 2017).

Finally, in the ongoing **SituLearn** ANR project which I am leading, we have once again improved the model by adding a collaborative learning scenario, but we have also developed a new authoring tool that combines the best of *JEM-Inventor* and *MOGGLE*. The SituLearn project is characterized by a broader scope, as it is intended to be used by teachers and by museums and cultural centers that cannot afford to develop custom applications. To facilitate the reading of this manuscript, we will refer to these mediators as "teachers" and to museum and cultural center visitors as "learners". We have also added functionality for teachers to view learners' progress and outcomes during and after field trips. *Figure* 3.9 summarizes the steps for using SituLearn: first the teachers create their smartphone application, then the students use this application during the outing and finally, the teachers can view their progress during and after the outing. This project was carried out in collaboration with ten pilot teachers and cultural mediators working in museums.

In this section, we will first examine the latest version of the ML game model which was perfected during the three projects. Then, we present the interfaces and main functionalities of the authoring tools *JEM-Inventor*, *MOGGLE* and *SituLearn*. Finally, we summarize the results of the experiments conducted during these projects.

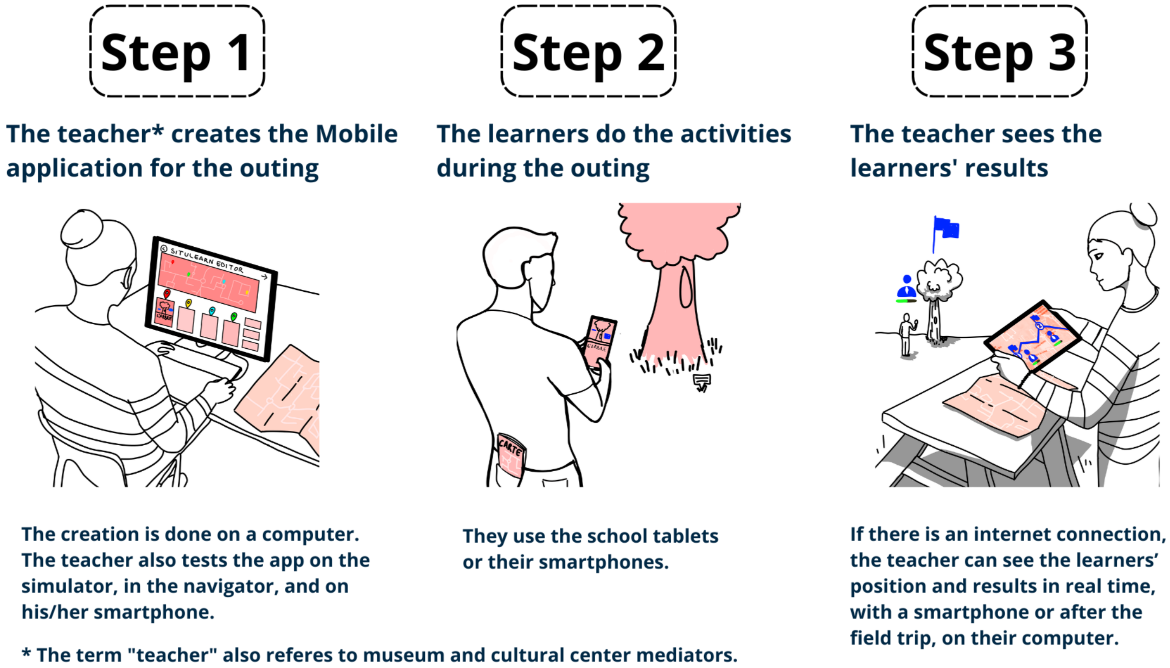

Figure 3.9: Steps for using the SituLearn authoring tool

3.2.1 Mobile Learning Game Model

The proposed ML game model is shown in *Figure* 3.10. It is also presented in detail in (Marfisi-Schottman et al., 2016b) and (Marfisi-Schottman et al., 2022a).

A ***Mobile Learning Game*** is composed of several ***Situated Game Units***, which are triggered when the players arrive at a ***Point Of Interest (POI)*** placed on a ***Map***. During the game, players collect points that are stored in their ***Score***. Teachers can also add a Timer that counts the time it takes players to complete the game and a ***Time Lock*** that shows how much time is left to complete the game. Players can also indicate that they **need help** at any time. A notification will be sent to all other students as well as the teacher.

Each *Situated Game* Unit is composed of:
- ***Instructions to Find the POI***: This instruction can include resources (text, images and multimedia), and various guidance features, such as displaying the POI marker on the map or a GPS beeper that indicates if you are getting closer or further away.
- ***Player at POI Validation***: This can be done by GPS (players must physically be in the geographic zone of the POI) (set by default if the field trip is outdoors), by scanning a QR code on the POI (recommended if the field trip is indoors), or manually by simply clicking on the button "I have arrived". Bear in mind that players can always force the validation in case of a technical problem (with the GPS or the QR code reader) or if the QR code has disappeared.
- ***Information sheet***: Teachers can provide information about the POI or the object of interest when players arrive at the POI. This information sheet can be consulted at any time during and after the game.
- ***On-Site Activities***: Teachers can propose several activities that need to be done at the POI. There are two types of activities. The first type is ***Answering a question*** (MCQ, picture MCQ

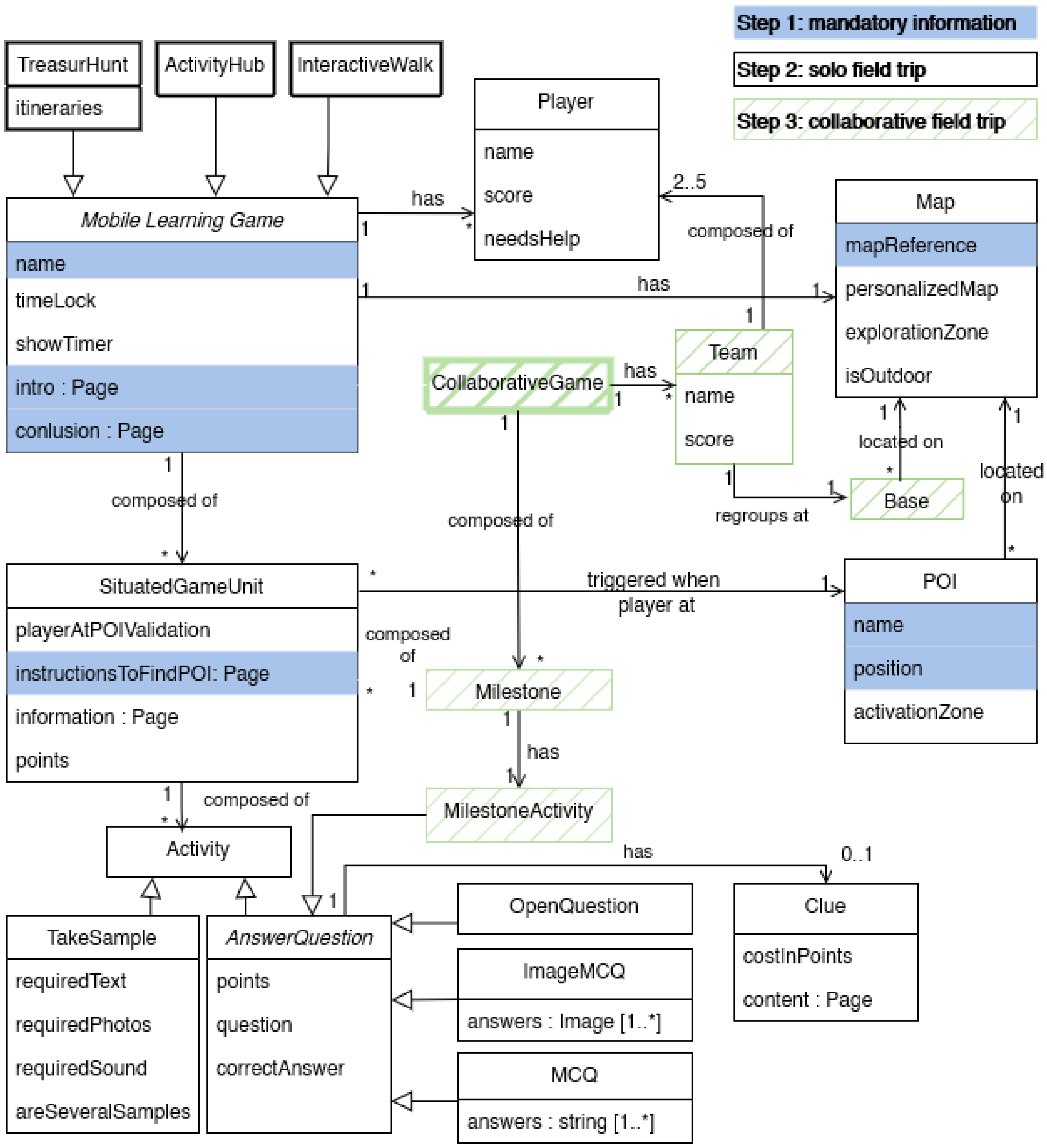

Figure 3.10: Mobile Learning Game model

or open-ended question). Players can earn points for answering correctly and they can also use points to buy hints if they need help answering the question. The second type of activity is called ***Taking a sample*** (photos, audio recordings or notes). These documents can be consulted at any time during and after the game and can be used by teachers during the debriefing session back in the classroom.
- ***Pedagogical Conclusion***: Teachers can provide a take-away message with the important knowledge freshly acquired at each POI.

This model allows to create three different types of *ML Games*, each suited to different types

of outings:
- Treasure Hunt: The *Situated Game Units* are in a defined order, i.e. the completion of one game unit triggers the *Instructions to Find POI* of the next unit. This type is well suited to most educational field trips organized by teachers. For this type of game, we have added the possibility of having several itineraries, corresponding to several different set orders of Situated Game Units. This avoids putting all students on the same path and allows teachers to discretely create more or less difficult itineraries to better adapt to the students' level. Several teachers have also used this feature to create complementary itineraries to encourage student collaboration during the class debriefing session.
- Activity Hub: All the units are visible from the beginning of the game so players can choose the order in which they want to complete them. This is particularly well suited for museum visits, as it is similar to an interactive audio guide.
- Interactive Walk: Players receive a notification when they are physically near a POI, asking them if they want to do the activities associate with that POI. This is typically the best game type for exploring a city, park or an archaeological site.

In the latest SituLearn project, we have also added the possibility to create a fourth type of ML game: a ***Collaborative Game***. This game model, represented by the green stripped boxes in *Figure* 3.10, includes several new concepts: students are grouped into ***Teams*** of 2 to 5 players and choose a name and a color. Each player's location is shown on the interactive map by a marker of their team's color. Each team has a ***Base*** camp from which they set out to gather information and then return. The game consists of several Milestones (3 to 5) related to one of the skills to be acquired during the field trip. Each milestone contains several Situated Game Units (4 to 10). The team members must coordinate their efforts to distribute these game units among themselves in order to win the most points in the allotted time. Students should use the strengths of each team member (i.e., speed and pedagogical skills) to decide who will complete which unit. Once all the game units are completed, team members must synchronize their return to the base camp. This unlocks the ***Milestone Activity***. This activity consists of a broad question that requires team members to analyze all the information and samples collected at the POIs and take time to reflect. This is a key moment of collaboration as team members will need to share the complementary information they have collected and explain their observations, then debate and make decisions in order to answer this final, big question. Teachers can also **make team scores available to all teams** to encouraging competition or, if the common goal is for all the teams to achieve a minimum score, to encourage collaboration.

The proposed model can easily be **extended by adding domain-specific modules**. This was the case in the ReVeRIES project, which focused on learning about plants. A specific ***Plant Recognition Activity*** was created (sub-class of Activity). To complete this activity, the learner had to find a specific type of tree and take a picture of one of its leaves. We used the image recognition module provided by one of the project partners to analyze the photo and automatically validate the activity (Jendoubi et al., 2020). We used the same system to extend the *player At POI Validation* method. This opened up the possibility for creating field trips that could be used in any forest or park where several common tree species could be found. In fact, this new extension made it possible to trigger activities not with a specific location, but rather when the players found a specific type of tree (e.g., oak, birch, elm).

The model presented above also comes with a complex **implementation model** that automatically takes care of triggering the right objects (instances of the classes in the Mobile Learning Game model) and interfaces depending on the players' actions, position, and progress in the game. This mechanism allows teachers to create geo-located smartphone applications without any programming skills.

3.2.2 Authoring tool for geo-located ML application for field trips

Jem-Inventor

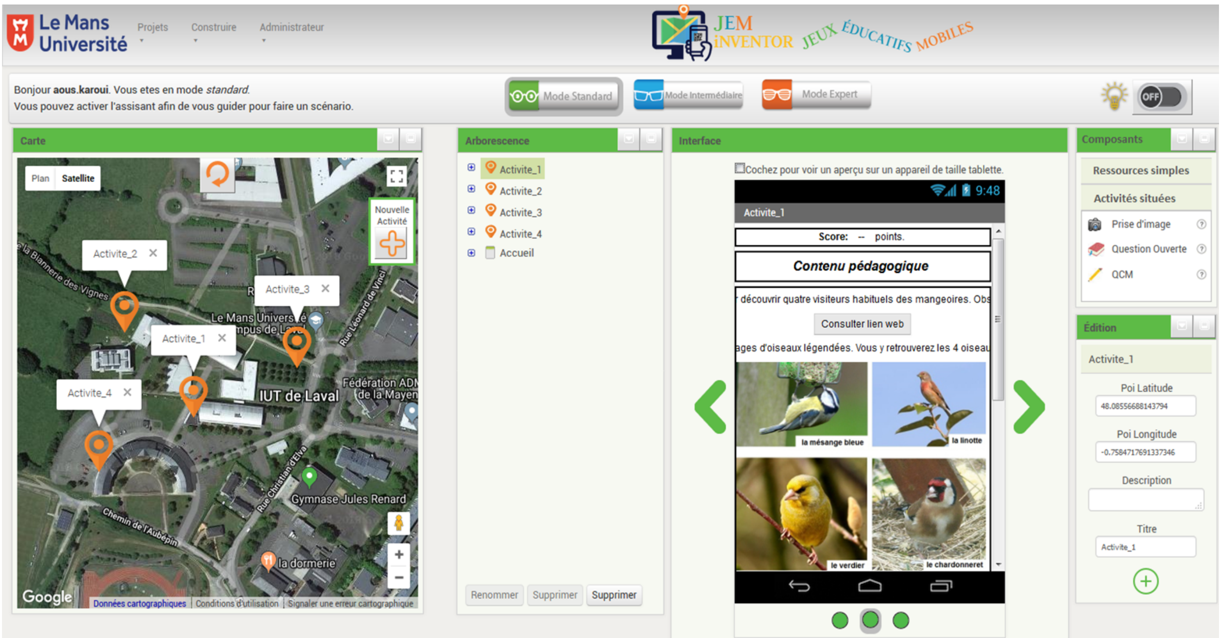

Figure 3.11: JEM-Inventor authoring tool interface

As explained above, the ML game model presented above was implemented in three different authoring tools. The first one was *JEM-Inventor* (*Figure* 3.11). Besides providing a simple WISIWIG (What You See Is What You Get) interface, its originality lies in its nested design approach. At the top of the interface, three buttons trigger different visualization modes. The *standard mode*, shown in *Figure* 3.11, provides a rather simple interface with only the most important functionalities. The *intermediate mode* adds more options and functionality to the panels on the right side, allowing teachers to further customize their game. Finally, the *expert mode* allows teachers to modify the core functionality of the game using visual block programming. The intermediate, and especially the expert mode, offer much more functionality and freedom but come with a much more complex interface. *JEM-Inventor* is entirely built on *App-Inventor*, an authoring tool designed by MIT to allow non-developers to create their own smartphone applications using block programming. This complex block-programming interface is only revealed in the last expert mode.

The experiments conducted with seven pilot teachers, three field trips, and more than 1 400 students (Karoui et al., 2020) show that the first two modes are very helpful for teachers to get started with the authoring tool, but at the same time they benefit from more powerful features when they need them. The third mode, on the other hand, was hardly used, although it motivated two teachers to sign up for professional training sessions to learn how to code. The WISIWIG interface was very useful for the teachers, although several of them expressed that they would have liked to try out the game in a simulator to get a better feel for what their students would see. They could do this on their phone, of course, but they insisted on the fact that this functionality should be on the computer to facilitate quick adjustments. Although we focused our efforts on the teachers, as we considered them to be the primary end-users of the application, we gathered some very positive feedback for the players who enjoyed the geo-located activities, the information provided when they arrived at the POIs, and the game mechanics.

MOGGLE

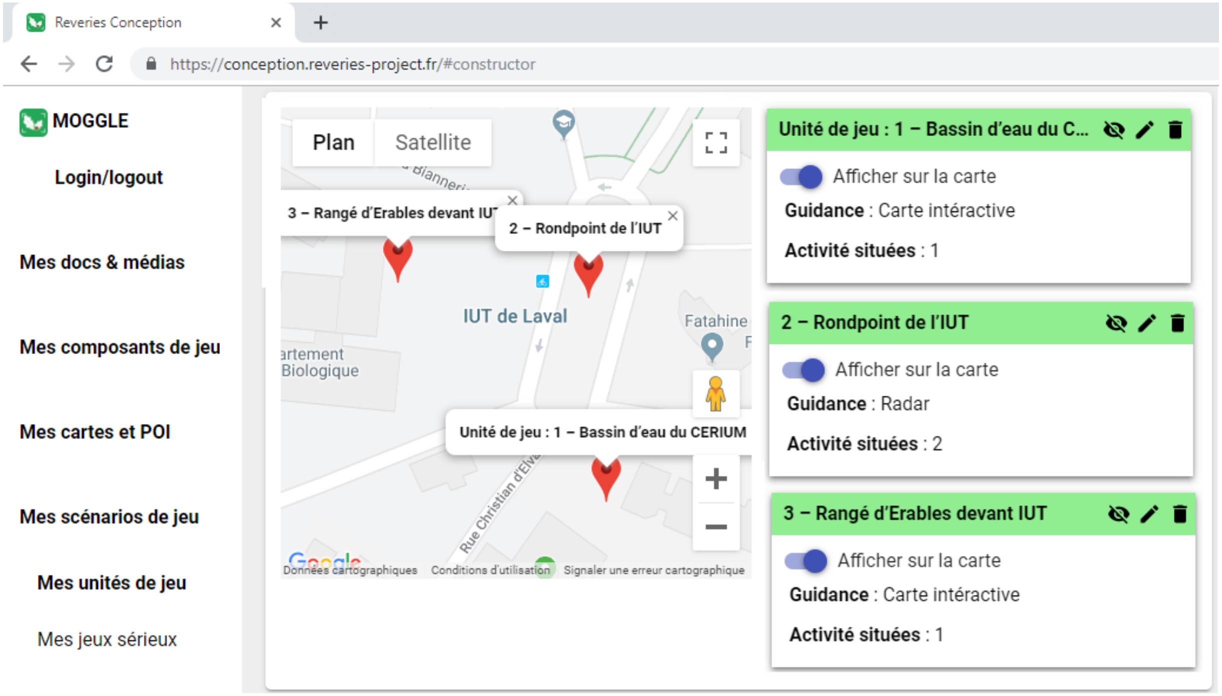

Figure 3.12: *MOGGLE* authoring tool interface

The model was then implemented in *MOGGLE*, an authoring tool specialized in ML games for learning about plants (*Figure* 3.12). One of the focuses of the *ReVeRIES* project was citizen science. The goal was to encourage all citizens to collect data about the plants around them, but also to contribute to the creation of fun and educational field tips. *MOGGLE* therefore implements several functionalities to allow teachers and botanical enthusiasts alike to create and share all or parts of their ML games. Thus, all elements presented in the model (*Figure* 3.10) can be shared, from the entire *MobileLearningGames*, to the *OnSiteActivities*, to the Information sheets, and even down to the image resources and POIs. As explained above, several specific botanical modules were also added to the model. Finally, we also implemented a preview of the activities, directly in the authoring tool, so that teachers could adjust the content on the fly.

As the end of the project coincided with the COVID pandemic, the large-scale experiments planned with 700 undergraduate biology students were cancelled. The four participating teachers had time to create the game scenarios for the Nantes botanical garden. We were also able to set up two smaller local experiments. One involved 10 participants in a local botanical garden, testing out the first prototype. And another, with 80 researchers, took place on our campus.

The goal was to get to know each other's labs and research topics to foster future collaboration. These experiments showed that the button-up design method we had chosen to facilitate resource sharing was frustrating. In fact, teachers had to create the resources, then the pages, then the situated activities, and combine them into a game unit that would eventually be integrated into the ML game. However, they appreciated the fact that they could share resources and preview the game.

SituLearn

Lessons learned from the previous authoring tools *JEM-Inventor* and *MOOGLE* were taken into account in the development of *SituLearn*. The goal was to provide a tool that could be used beyond research experiments, so we found additional funding to pay an external contractor to develop a professional quality application. The current version of *SituLearn* implements all the elements of the ML game model, except for the collaborative game. In comparison, *JEM-Inventor* and *MOGGLE* only implemented simplified versions of the Treasure Hunt scenario.

SituLearn has a simple interface, inspired by *Jem-Inventor*, with a top-down design method (*Figure* 3.13). Teachers first create their map (*OpenStreetMap* by default, but they can upload a custom map) and define the POIs. The Situated Game unit for each of these POIs is automatically created and teachers simply have to provide the instructions for finding the POI. In fact, our experience with the previous projects and the co-design sessions conducted with seven new pilot teachers allowed us to identify default values for almost all of the elements in the model. In *Figure* 3.10, the seven mandatory items that teachers need to fill in are highlighted in blue: teachers only need to provide a *name*, a *map*, an *intro* and *conclusion* page for the ML game, and a name and position for each POI plus *instructions on how to find it*. That is all! As explained above, the authoring tool integrates a standard Mobile Learning Game model and an implementation model that automatically takes care of creating the smartphone application. As with *JEM-Inventor*, the default interface shows only the basic, simple functionalities, but the others can be accessed in the options buttons. Like *MOGGLE*, *SituLearn* offers an online simulation for teachers to pre-visualize their game, and they have the possibility to share their entire game or just a situated game unit with other teachers.

SituLearn offers several other functionalities that should increase its likelihood of acceptance in schools and museums and, to our knowledge, they are not offered by other ML authoring tools. For example, the ML game scenarios can be downloaded to tablets or smartphones for use without an internet connection. This is mandatory for the use of tablets in schools, but also very useful for museums which are often located in old castles and buildings with very thick walls that block the WIFI. *SituLearn* has also been developed as a *progressive web app*, which means that it does not require the installation of an application from an *App Store*. Again, this is very useful for schools and museums that have secure tablets and these devices require a significant amount of paperwork and time to install a new app. Finally, users can play a ML games without having to create an account with a valid email, as this is a major barrier to the adoption of digital tools for tourism.

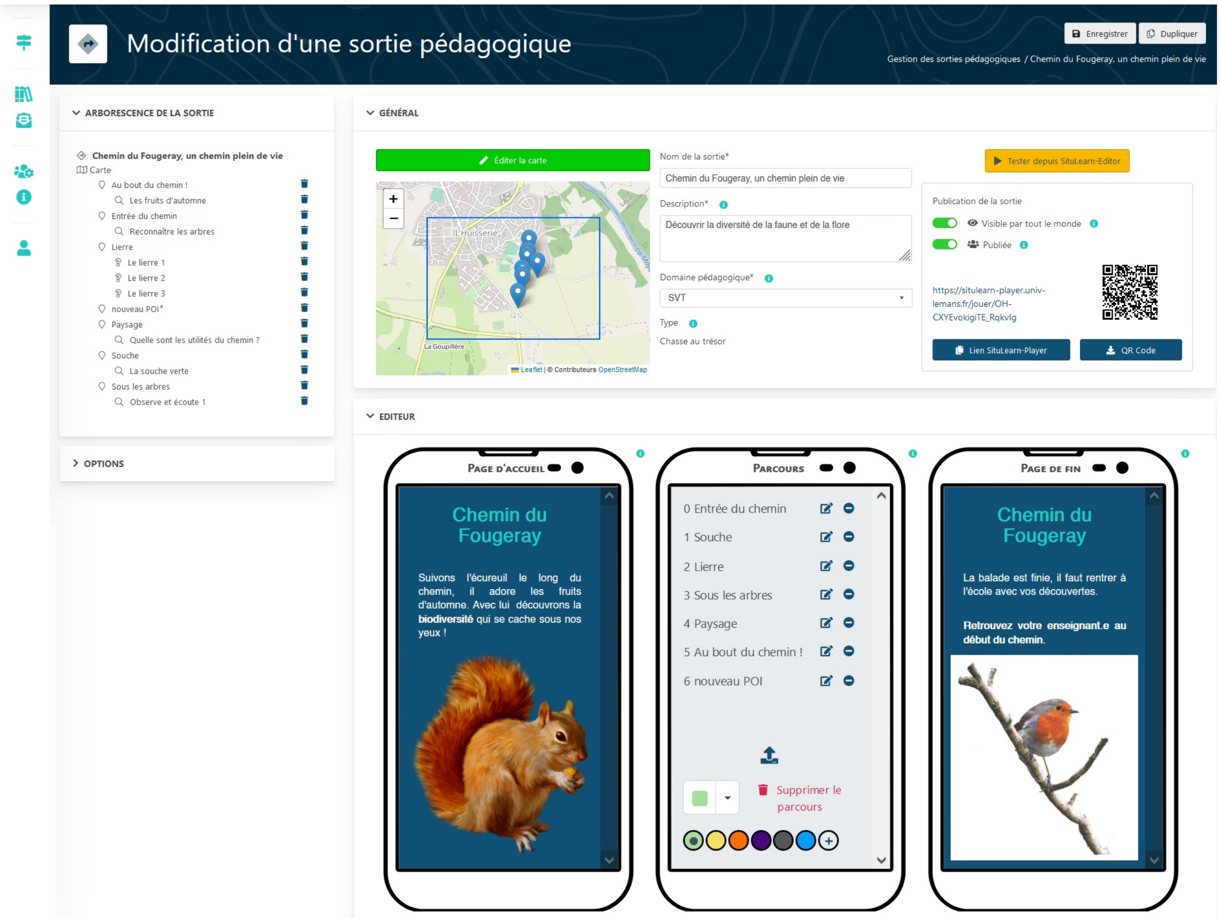

Figure 3.13: SituLearn authoring tool interface

3.2.3 Helping teachers explore new teaching paradigms

As mentioned in the introduction, one of the main design challenges of authoring tools is to help teachers improve their teaching methods by exploring new paradigms. We propose several scaffolding techniques to encourage teachers in this direction.

First, we put a lot of effort into making *SituLearn* as easy to use as possible. The goal is to lower the height of the first rung of the ladder. This was done by providing simple interfaces that initially show only the basic functionalities, and by creating several tutorials and guides, available as videos on the project website but also embedded in the authoring tool, in the form of more than 40 information bubbles ("i" icons in *Figure* 3.13). In addition, the ML game model presented above is very well suited for easy implementation of field trips, just as they are currently carried out by teachers and cultural mediators. Research has shown that the most time-consuming aspect of using authoring tools is the creation of content. This poses a significant risk of abandonment, but can be circumvented by using content from other sources (Chakraborty et al., 2010). Teachers can therefore use existing educational material to easily create their first ML game with *SituLearn* and test the tool.

Once teachers have created their first ML game with pre-existing content, the next goal is to encourage them to improve their field trip. This process can be thought of as a ladder with rungs placed at strategic intervals to help teachers progress at their own pace. The second rung is very easy to reach because the default settings suggested in *SituLearn* automatically add game mechanics. *SituLearn*'s nested design approach, which progressively reveals more functionality, also encourages teachers to go further by including different types of activities, such as image MCQs or Taking Samples that they might not have thought of otherwise. Finally, the model is very flexible and adaptable, so teachers can easily add elements and improve their initial ML game. The model can also be easily extended by computer scientists if the teachers are in need of domain-specific activities or functionalities.

3.2.4 Experiments of SituLearn

More than 21 ML games have been created so far with *SituLearn* by the pilot teachers and mediators of the project. *Table* 3.1 and 3.2 show their different profiles and educational domains (science, history, geography, geology and sports). *Figure* 3.14 and *Figure* 3.15 also show two of their testimonials (the others and in the Appendix). The educational objectives of these outings ranged from learning how to find one's way on a map to more complex skills in geology and botany. *SituLearn* can also be used to create scenarios for tourism and vocational training. The 1 356 players who have used *SituLearn* range in age from preschoolers to adults.

Table 3.1: Mobile Learning Games created by pilot teachers and mediators with SituLearn (first part)

Creators of the ML games	**Discipline and learner age**	**Educational goal**	**Name of the ML games**	**Nb. of learners**
Two Pre-school teacher	Discovery, 3 to 5 years old	Learn how to orient oneself with a map and collaborate	Letter hunt in the humid zone	18
Volunteer in a nature association and primary school teacher	Natural sciences, 9 to 11 years old	Discover and learn how to observe nature	Discover the Fougeray path in autumn	46
			Discover the Fougeray path in winter	45
Middle school teacher	Natural sciences, 11 to 15 years old	Discover nature and traces of early human settlers	Science missions at Saulges	48
		Work-out and review basic notions about calories and sports	Row in fifth grade	150
			In the heart of Christmas	75
			Challenge: "My Olympic Body"	150
		Study climate and weather	Climate and weather	75
		Discover nature	The treasures of the Coupeau	150
		Learn how to recognize common tree species with a determination key	Aubepin path	28
			Scots pine	24
			Determination key	24
		Test a new organization of the class	Natural sciences workshops	75
		Discover and identify common natural materials	Game to discover natural materials	75
	Parents of the students	Discover the teacher's original teaching method	Science at Jules Renard middle school	30
	Adults training to be track jury members	Learn how to identify the parts of a stadium	Stadium and track jury	4

Table 3.2: Mobile Learning Games created by pilot teachers and mediators with SituLearn (second part)

University teacher	Graduate students in geology	Learn how to do on-site observations, identify rocks and create a geological map	Geological terrain of Saint Leonard des Bois	16
	Introduction to Geology for adults	Learn how to identify common rocks and geological formations	In the steps of a geologist	6
One sports and one history/geography teacher at a teacher-training school	Future middle school and high school teachers	Discover the morphology of an urban space, locate and orient oneself in space, produce a cartographic map	Concept of "living" and orienteering race	72
Teacher in as specialized medical-education institute	Young adults with various physical and mental handicaps	Learn how to orient oneself in space using a digital tool	Orienteering race at the Monod park	5
Mediator at the Departmental Archives of Mayenne	Families	Discover the archives, their mission, history and the original building	Discovery of the Archives on Heritage Day	240
10 pilot teachers and mediators	**Various disciplines**	**Large variety of educational goals**	**21 Mobile Learning games**	**1356 learners**

Figure 3.14: Testimony of a middle-school teacher who used SituLearn

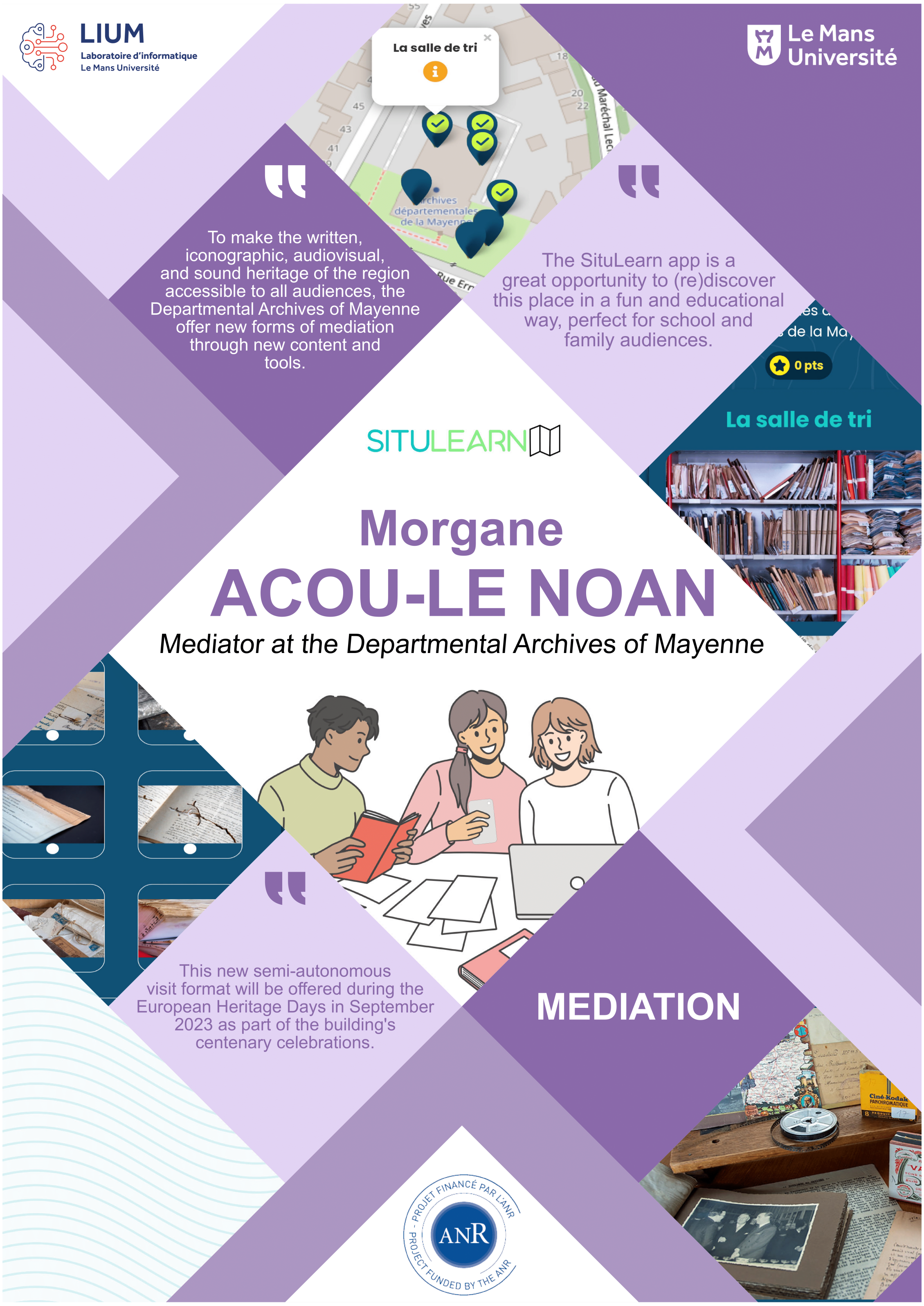

Figure 3.15: Testimony of a mediator who used SituLearn

These first experiments, conducted this year, allowed us to verify the **usability** of *SituLearn* from the teachers' perspective, but also from the learners' perspective. The design sessions of all the pilot teachers were videotaped and analyzed. All pilot teachers then participated in self-confrontation interviews conducted by our social science colleagues. After several iterations of development and testing, the final interfaces were found to be **satisfactory in terms** of usability for both teachers and players. In addition, the ML games created are very different from each other. They cover all the types of ML games offered by *SituLearn* (treasure hunt, activity hub and interactive walk) and use a wide variety of functionalities. For example, some teachers used the timer lock to make sure the students would get back to class on time, some removed all points and scores because they did not want to encourage competition, some used QR codes and others only GPS validations for arriving at the POIs. After participating in these experiments, the pilot teachers requested some new functionalities that will be added to *SituLearn* in the coming months, but we can say that the tool seems to be **powerful** enough to cover all their different needs and contexts of use.

The **usefulness** of the tool also seems to be more than satisfactory, as several teachers have created more than one ML game, although they only agreed on one when they signed up as pilot teachers. All of them have also stated that they would reuse their ML game or create new ones for next year. The **impact** of *SituLearn* was analyzed by comparing field trips that were conducted with and without the tool. The entire field trips were videotapes, both from the teacher's and the learners' perspectives. The interactions, especially the way the teachers helped the learners, were annotated in detail. Video analysis takes a long time and has not been completed for this project, but the first results show that the use of *SituLearn* has an impact on the organization of the activity. Field trips organized without *SituLearn* were much more teacher-centered and had long periods of explanation, whereas those organized with *SituLearn* were learner-centered and the teacher would provide shorter explanation, as the knowledge was distilled through the ML game. The reactions of the teachers who created the ML games, and the other teachers who were simply accompanied the group of learners for safety reasons, seemed to be influenced by the used of the ML game. The teacher-authors tended to give much more freedom to the learners, whereas the chaperoning teachers tended to encourage the learners to carefully follow the instructions given by the application or provide information that was sometimes unrelated to the objectives of the ML game. These observations should help us provide guidelines for the use of ML games in educational field trips.

Finally, the **scaffolding techniques** cannot be experimented with the pilot teachers because they are too familiar with the model and the interface of the tool they have helped to design. This will be done next year with several new teachers. Fifteen teachers have already spontaneously signed-up and started creating ML games on *SituLearn*. We also intend to experiment with a class of novice teachers to compare how these teachers use the application compared to the first, more experienced and highly motivated teachers.

3.2.5 Discussion and positioning of the work

The experience gained in the course of three consecutive projects on ML game models and authoring tools has allowed us to reach a certain maturity in this area. This raises the question of what to do once a research branch is fully developed. Ideally, the results of our research should now be transferred to the community so that the tool can be widely adopted by teachers. However, this requires an application hosted on a large server, with technical maintenance and a minimum of support service for users who have questions. This is clearly beyond research! The application must therefore be transferred to an entity (association or company) that can provide these services, while ideally staying in contact with the researchers in order to continue large-scale and long-term research (the grail of TEL).

Our efforts to transfer *SituLearn* over the last year show that this is not so easy, especially if you have a utopian vision of making the results of public research (like *SituLearn*) available to the public free of charge. But I will not give away too much information here, because the next and final chapter develops several initiatives that, I am sure, you can hardly wait to read!

3.3 Design methods for creating authoring tools

The research presented in this section addresses the following research questions:
- RQ12. What design principles apply to TEL authoring tools?
- RQ13. What guidelines can facilitate the management of authoring tool project?

As explained in the introduction, we propose to use our experience in authoring tool design (four previously presented projects) to provide not only some design principles for authoring tools, but also guidelines for managing an authoring tool project.

3.3.1 Designing principles for TEL authoring tools

As with the TEL systems presented in *Chapter* 2, the experiments conducted with teachers and their learners allowed us to identify several functionalities that seem to be necessary for all types of TEL authoring tools. This list should not be considered as exhaustive. It is simply extracted from our experience with the four projects presented above.

- **Preview functionality**: Teachers need to see what their students will see when they use the applications. Therefore, it is important to include a preview functionality to the authoring tool that shows the final results, especially if the designed TEL system is interactive. This functionality should also be directly in the application so that teachers can easily adjust the content and immediately view the repercussions.

- **Clear design steps**: It is important for teachers to have a clear design workflow with steps that are indicated or a gauge that tells them how far they are from the finish line. For authoring tools that are more complex, it is important to at least show all the mandatory information that needs to be completed.

- **Templates, examples and guides**: Teachers should be able to create their first activity or scenario as quickly as possible (the first rung of the ladder). The use of templates, predefined content, examples and guides can therefore be very useful.

- **Possibility of sharing content**: A new TEL system is more likely to be adopted if a community of teachers is working with it. It is therefore wise to encourage the creation of such a community by including tools for easy sharing of content. When the authoring tool is mature, setting up social media and training sessions is a good way to help this community grow.

- **Accessibility on as many devices as possible**: If the intention is for the authoring tool to be used as widely as possible in schools, it is essential to take into account the material currently used in these establishments and their constraints. In France, schools are equipped with a wide range of safe-guarded tablets (android, surface) and computers, some of which are very old, and there is not always a WIFI connection. We therefore decided to use progressive web applications that are accessible on any web browser (without installing an application from an App store), and that only require the Internet for the initial connection.

3.3.2 Guidelines for managing a project on authoring tools

The four guidelines for managing authoring tool research projects are summarized in *Figure* 3.16. Compared to the previous design principles, these focus on the partners that should be involved in the project and how they should interact, especially during the co-design sessions.

Figure 3.16: Four guidelines for designing TEL authoring tools

Guideline 1. Implicate a reasonable number of representative pilot teachers

Involving pilot teachers in the design process of authoring tools is one of the main guidelines provided in the literature (Murray et al., 2003), but our experience shows that they should not be recruited randomly or simply because they volunteered. In fact, it is important to have a representative selection of pilot teachers to insure that the authoring tool meets a **representative range of needs**. If possible, the group should also include an equal number of women and men, from novice to experienced teachers. It is also important to recruit teachers who consider themselves "uncomfortable" with technology. It may be harder to obtain the participation of this last category, as they tend not to volunteer for TEL projects, so one should consider recruiting using the snowball technique, i.e., by asking volunteer pilot teachers to recruit among their colleagues.

The **group should also not be too large, in order** to facilitate the organization of personal design sessions. Based on our experience, a minimum of six to a maximum of 20 teachers should be recruited at the beginning of the project. More pilot teachers can be added in subsequent iterations, but even working with 20 teachers during the design phases can be a challenge.

A **contract** is a good way to ensure that pilot teachers know what will be required of them, such as participating in several co-design sessions, using the authoring tool to create a learning session, and participating in several experiments with their students. We insist that **pilot teachers should plan to use the authoring tool with their students in one of their current classes**. This method is an effective way of getting them to feel involved in the project (Saar and Laanpere, 2022). It supports teachers in developing and improving their current practice based on their students' learning needs, their own learning needs, and the impact of their practice on student learning and achievement. The contract should also explain what they will get in return, and this is where it gets tricky because apart from citing them in academic papers, on the project website and expressing our eternal gratitude, there is not much we can offer! European research funding does not provide easy solutions to pay them. However, it is possible to lend them equipment (tablets, computers and smartphones). As we will discuss in the last guideline, teachers can sometimes count their participation as hours of professional training if their school or education district is involved in the project (Vanari et al., 2019). The only thing that can be promised is the creation of an authoring tool that will allow them to improve their teaching. However, in the context of a research project, we are never sure of the final outcome and the tool may not meet their expectations. Therefore, it is important to **promote the research process** rather than the result, and the completion of each model, prototype, and research paper should be celebrated together as another step toward a common goal.

Guideline 2. Collect a large variety of practices.

When designing authoring tools, the first iteration of the design session aims to collect a wide **variety of practices** (compared to other TEL systems where one or two practices are enough). These practices can be collected in different ways, such as observing or asking the pilot teachers what they already do and what tools they use. Usually, however, the aim is to create new practices, otherwise it would not be research. Pilot teachers therefore need to imagine what they would ideally like to do. As presented in the last chapter, we strongly recommend the use of prototypes and application examples to help teachers test out the technology and understand what it can offer. The use of paper prototypes combined with a video of the pilot teachers explaining their idea is a good way to understand the functionalities that might interest them.

This complex design session can be supported by several tools and methods. For example, in the MIXAP project, we suggest the use of specific materials and notations to create paper prototypes that are easier to understand and compare (Ez-Zaouia et al., 2022). We also used a four-step method to encourage collaborative thinking. Each pilot teacher was requires to:
- Step1. Test a variety of MR tools to see what this technology could do.
- Step2. Design a paper prototype of the desired TEL system for their class.
- Step3. Walk around the room to read each other's paper prototypes design and add comments, using post-it notes, if something seemed unclear or to make suggestions.
- Step4. Draw up the final version of the paper prototype, taking into account the comments of their peers.

In the ReVeRIES project, we did not have a large number of pilot teachers (only three). We therefore proposed a brainstorming method to encourage the pilot teachers and researchers to imagine new educational situations and ML scenarios that could be proposed. To make this design process more fun and productive, we turned it into a board game with a board that represented a real park and its trees and the designers drew a card that defined their learner profile persona (Marfisi-Schottman et al., 2016a). The dice were also used to determine the movements of the players (some slower than others, depending on their profile) to help the designers imagine the most appropriate scenario.

Guideline 3. Co-design the generic models with the pilot teachers

The paper prototypes produced and the ideas collected during the design session need to be analyzed to find common functionalities or patterns to build the generic model. Even if this part needs to be done by computer scientists who are used to factorizing everything (occupational hazard), the generic model still needs to be validated and refined with the help of the social science researchers and pilot teachers in the project.

This can be done by explaining the UML (Unified Modeling Language) diagram, but it is tricky. We tried this technique in the *ReVeRIES* and *SituLearn* projects by building the diagram step-by-step with post-it notes on the board, but this was still difficult for teachers to relate to. Ideally, this should be combined with an explanation of how the model implements each of the teacher's paper prototypes. This improved technique, used for *MIXAP*, proved to be much clearer for the pilot teachers and also richer in terms of discussion.

And discussion is key to **reaching a consensus on the model**. This is crucial because the authoring tool will be built on this model, and redefining the model at a later stage could result in months of redevelopment and delay. In particular, the team must decide which functionalities are generic enough to be included in the model and which are too specific and should not be included because they would unnecessarily complicate the authoring tool. For our four projects, we decided on the following rules: If the functionality is needed by more than one pilot teacher, then it should be included in the model. And if the functionality is needed by only one of the pilot teachers, it should be discussed with the group. Either it is considered too specific and the pilot teacher in question agrees to drop it, or another teacher finds it interesting and it is included in the model.

We insist on the importance of face-to-face design sessions for this critical phase. We were not able to gather all teachers at the same time for the *SituLearn* project, for example, and this resulted in us having two sessions that did not reach the same consensus, leading to several iterations of the design and considerable frustration.

Guideline 4. Team up with a teacher training institution

Finally, the last recommendation is to work with a teacher training institution. They can be very helpful in the six most critical moments of the project. First, they can help recruit pilot teachers, since they are in contact with many teachers of different profiles. Second, they are familiar with local, practical constraints and institutional personalities that could participate in the project. This can help to build long-term partnerships for the development and dissemination of the tool, but it can also make it easier to give teachers credit for their participation in the project so that it counts as part of their professional training. Third, they have experience and resources to help communicate about the project. They can help write documents and create videos to promote the project to school principals and parents, and this plays an important role in the adoption of TEL (Dias and Atkinson, 2001). Fourth, they are used to talking to teachers and understanding how they work, and they have also worked with researchers, which makes them the perfect candidate for the role of **broker**. This figure represents someone in between two worlds who can facilitate the creation of a shared praxeology (Aldon et al., 2013). Recall that we mentioned this in *Chapter* 2 regarding DBR. Fifth, they usually have spacious rooms with paper boards and all kinds of equipment for their teacher training programs, which is perfect for organizing the co-design sessions. And sixth, if you are still not convinced, they can help design tutorials and videos when the authoring tool is ready to be released into the wild for other teachers to use.

For the *MIXAP* project, we partnered with *Canope*, a national teacher training institution. Their help greatly facilitated the organization of the project and accelerated the production of the authoring tool. In addition, they will use the *MIXAP* authoring tool in several of their teacher training programs in France next year, and this will be a great opportunity to continue the research on a larger scale. They have also led the way to future collaborations with the department of the Mayenne and, on a larger scale, with the Brittany and Pays de la Loire educational region.

3.3.3 Discussion and positioning of the work

Authoring tools are still quite rare in TEL projects. This is quite understandable, since they are substantially more complicated to create than custom TEL tools for one context. They require the involvement of a large team of pilot teachers, which imposes many organizational constraints. They also need to be built on solid design principles that typically take years of research to mature, and they require the effort to create simple, intuitive interfaces and user guides. Authoring tools are also harder to evaluate than other TEL tools because there is no guarantee that teachers will use the model to its full potential. This can be quite frustrating (true story).

However, I believe that authoring tools are the future of TEL research because they **put teachers at the center of the design** by allowing them to update and reuse TEL systems. Authoring tools can also play an important role in the **social relationship between TEL researchers and a potentially very large community of teachers** to create meaningful tools and increase their effective use in schools. These claims are supported by a very recent comparative study we conducted with researchers working on instructional design projects. These are exclusive results you are about to read! We used a questionnaire based on the Knowledge Appropriation Model (KAM), an instrument capable of predicting the intended adoption of new learning practices by measuring several social constructs, such as a the teachers' *intrinsic motivation* to use this new learning practice or their sense of *ownership and belonging* to the project (Ley et al., 2020). For example, the sense of ownership is measured by the response to several statements such as "I feel the need to defend the [method, innovation] if it would be criticized" and *belongingness* is measured by statements such as "'I feel I am a part of the learning community consisting of teachers and researchers working on the [method, innovation]" (Ley et al., 2022). Information was collected through questionnaires completed by more than 112 teachers who had participated in instructional design projects. Three groups of projects were compared: the French authoring tool projects (MIXAP and SituLearn), the Innolab projects, and the School University Partnership projects (Arhar et al., 2013). The main difference is that the latter two categories of projects did not focus on one authoring tool, or even on technology, whereas teachers participating in MIXAP and SituLearn were limited to using the co-designed authoring tools. For example, several projects addressed the use of robots in middle school and pre-school but did not target a specific type of robot or activity. Other projects did not emphasize technology at all. The other difference is that, unlike MIXAP and SituLearn, which include a wide variety of teacher profiles, the other projects targeted teachers working in the same school and discipline.

However, as shown in *Figure* 3.17, the scores for these three types of projects are all very good. After running a Kruskal-Wallis test and an Anova test, the only statistically significant differences found between the School University Partnership projects and the French authoring tool projects were in *Intrinsic Motivation* ($p = 0.014$) and *Knowledge appropriation* ($p = 0.024$). The French projects were slightly lower on these two constructs. Nevertheless, these results are very encouraging. They could show that authoring tools are capable of creating a sense of community and acceptance within a potentially very large community of teachers, and that these feelings are almost as strong as those created by custom instructional design projects that target specific teacher profiles and include a wide range of digital and paper-based tools. More research needs to be led to verify this.

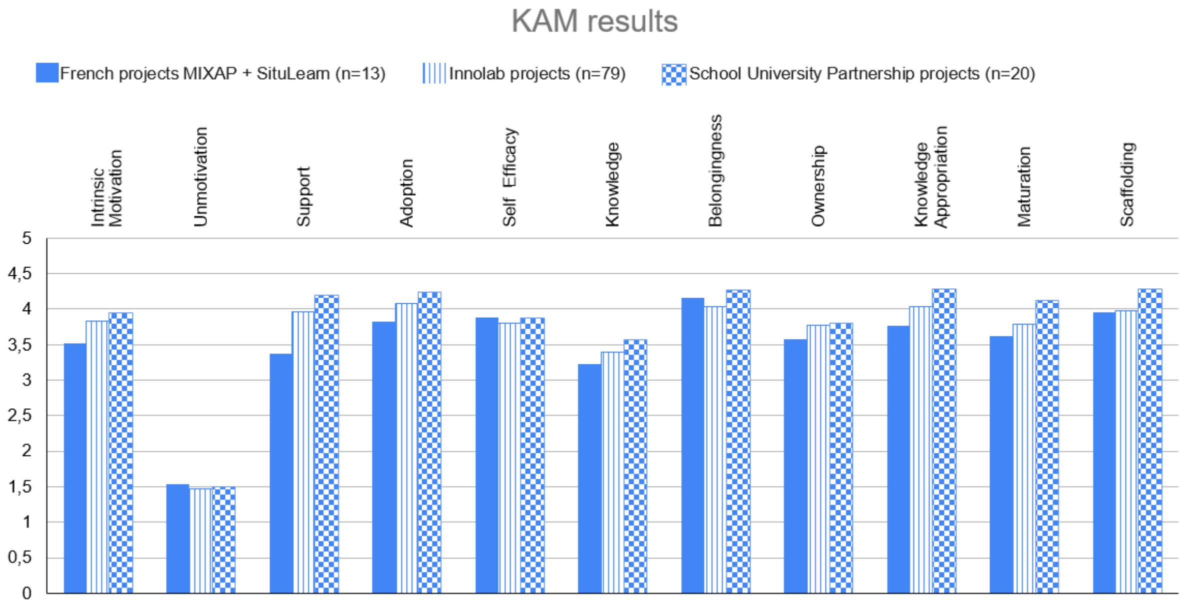

Figure 3.17: Comparison of teacher involvement between three types of research projects

Finally, the creation of authoring tools also has a philosophical implication. Murray argues that "we should consider ourselves promoters of educational reform and transformation since these tools are not so much helping teachers and educational developers more easily or cost effectively do something that they already do, rather, we are offering them the possibility of creating something entirely new" (Murray, 2004).

4 Conclusions

In this chapter, we review several contributions related to **adaptable models and authoring tools** for TEL. First, we present the main advantages of authoring tools: teachers create their own content that is adapted to their needs, they can easily update this content to reuse the TEL system, and they do not need any resources to do so. However, **authoring tools also raise major design challenges**. First, it is very difficult to design an authoring tool that is powerful enough to meet the needs of a large number of teachers while keeping the interface and the design workflow very simple and easy to adopt. The second challenge is to provide optimal UX design, guidance modules and scaffolding to increase the perceived affordance of the authoring tool and to encourage teachers to try out new teaching techniques that are made available.

We attempted to address these design challenges through four research projects. With the help of pilot teachers, we were able to provide adaptable models and authoring tools that help teachers create their own original TEL systems in two domains.

In the domain of HCI for education, we have developed original, powerful MR educational activity models (Ez-Zaouia et al., 2022) and a very simple authoring tool (Ez-Zaouia et al., 2023) that allows teachers to use MR to enhance their courses from preschool to university.

In the domain of ML and SGs, we have developed a comprehensive adaptable model for ML games that has been progressively improved, over a ten year research period, involving more than 21 pilot teachers (Marfisi-Schottman et al., 2022a). We have developed several authoring tools with this model to test out different design strategies and scaffolding techniques to help teachers use the ML and game mechanics embedded in the model, to their full pedagogical potential. The final authoring tool, called *SituLearn*, is more than a research prototype and is ready for being used by the general public.

Based on our experience with these projects, we also propose a **set of design principles for TEL authoring tools** and **practical guidelines for managing research projects on authoring tools**.

TAKE AWAY MESSAGE

This third chapter reports on our efforts to achieve our second researcher objective (RO 2): provide adaptable models and authoring tools to facilitate TEL development and increase their acceptability and use.
We first point out the five major advantages of authoring tools:

- They cover a wide range of needs and can therefore be used by a large number of teachers.
- They allow collaborative design of TEL systems and the creation of a community of users.
- They produce ownable TEL systems (sense of ownership) as teachers create their own custom content.
- They produce reusable TEL systems as teachers can modify and update the content.
- They produce cheap TEL systems since teachers do not need any other resources or staff.

And their two design challenges:

- It is difficult to create authoring tools that are powerful AND easy to use.
- It is difficult to encourage teachers to try out new teaching methods and use the tools to their full potential.

For the domain of HCI for education, we propose:

- Original Mixed Reality educational activity models suitable for preschool to university.
- A very simple authoring tool (*MIXAP*).

For the domain of ML and SGs, we propose:

- An extensive ML game model for situated learning.
- A powerful, robust and user-friendly authoring tool that enables teaches to create their custom geo-located applications for field trips and is also adapted to museums and tourist offices (*SituLearn*).

Finally, we propose design principles for TEL authoring tools and guidelines to manage such research projects.

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CHAPTER 4

Conclusion and Research Perspectives

Bridging the gap between technology-enhanced learning research and society

Chapter 4

Conclusion and Research Perspectives

Bridging the Gap between Research in Technology-Enhanced Learning and Society

This chapter briefly reviews our main research contributions before focusing on my research perspectives for the upcoming years.

Contents

1 Review of contributions

All of our contributions, presented in this manuscript, articulate around two main research objectives (*Figure* 4.1):

- RO 1: Provide methods, models and tools to help all the necessary actors design effective TEL systems.
- RO 2: Provide adaptable models and authoring tools to facilitate the development of TEL systems, and thus increase their acceptability and use by teachers.

Several contributions are proposed to achieve the first objective. First, we propose a number of **design principles** for using game mechanics, ML and HCI for various educational objectives and contexts. In the TurtleTable(t) project, we explored the use of collaborative game mechanics and tangible objects to teach middle school children the basics of computer programming. In

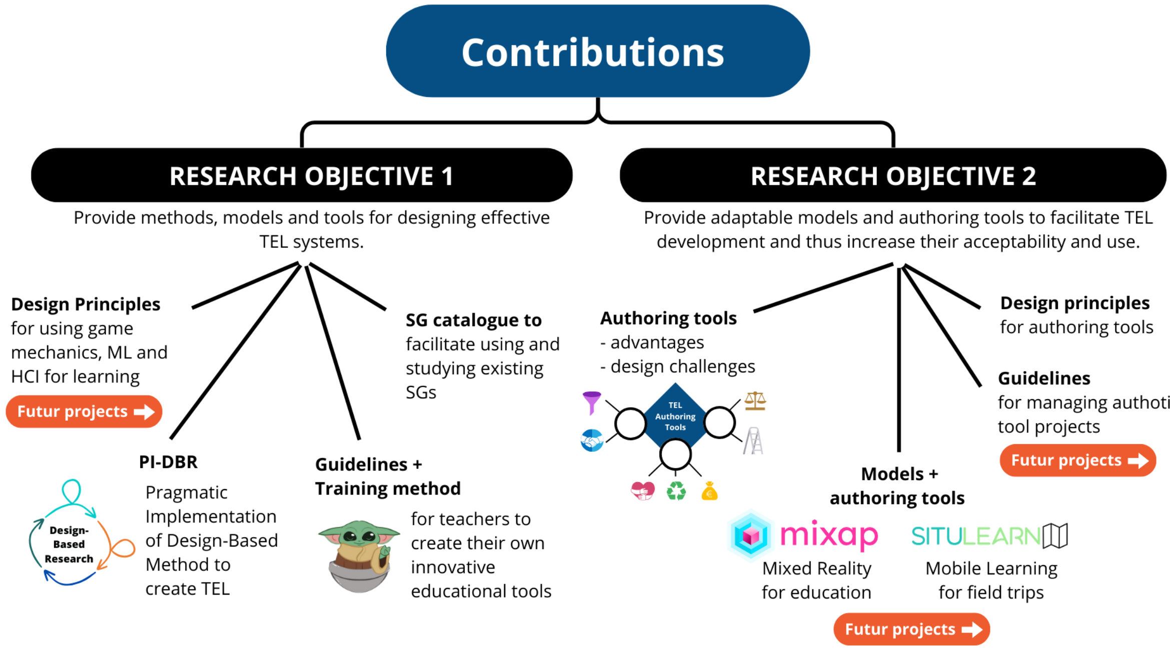


Figure 4.1: Overview of contributions

the SMART-Fractions project, we used game mechanics and Mixed Reality to teach children how to understand the notion of fractions on a number line. And in TGRIS, we used Virtual Reality to help professionals deal with their emotions in complicated situations. Based on our experience, we also propose **PI-DBR, a pragmatic implementation of the Design-Based Method (DBR), with gradual implication of researchers and teachers**, for conducting such research projects. In the same chapter, we also propose an automatically-updating catalogue, called *JEN-Planet*, which currently contains more than 800 SGs. The objective is to help teachers and researchers find existing SGs either to use them or for inspiration and analysis. To create this catalogue, we defined the **LGMD metadata schema** which describes the educational properties of SGs with an optimal number of description fields, the **ADEM indexing model** which is capable of automatically scraping the information for these fields on web sites and the **UDID interface design method**, which we used to design the catalogue's interface with teachers. Finally, we propose **guidelines** and a **training method** to help teachers create their own original educational tools, including SGs (digital and non-digital). The objective was to take advantage of the available resources and staff. This method was developed over a seven-year period of leading the Ludifik'action professional training course and has produced more than 32 educational tools that are currently used in universities and schools all over France.

Several contributions are also proposed to achieve the second research objective which is to provide adaptable models and authoring tools to facilitate the development of TEL systems, and thus increase their acceptability and use by teachers. First, we clearly **identify the advantages of authoring tools** and argue that these tools are a good solution to advance TEL research, but also to democratize the use of TEL in schools. We also **identify two main challenges** that need to be dealt with when creating such authoring tools. First of all, it is very difficult to create authoring tools that are powerful and, at the same time, simple and easy-to use. Secondly, teachers naturally tend to use technology to simply recreate their current learning paradigms and it is very challenging to get them to try new teaching methods and use these tools to their full potential. We propose to tackle these design challenges for two specific types of TEL. Our first contribution is an original **Mixed Reality educational activity model**, suitable for use in preschool to university with its **very simple authoring tool**, called *MIXAP*. It was designed and tested with the help of 20 pilot teachers and the Canopé teacher training network. Our second contribution is an **extensive ML game model** for situated learning and a **powerful, robust and user-friendly authoring tool**, called *SituLearn* that enables teachers to create their custom geo-located applications for field trips. This tool uses a nested design approach that enables teachers to easily get started with the tool, by designing a simple scenario, and then gradually refining and customizing it with more options and functionalities that are progressively revealed when the teachers need then. The ML game model was refined and improved through three consecutive research projects (that went on for ten years in all). Three versions of the authoring tool were also developed and tested with more than 21 teachers and 2 000 learners to determine the best design workflow, scaffolding techniques and UX-design to encourage teachers to innovate. *SituLearn* is now more than a research prototype and is ready to be transferred not only to the teacher community, but also to museums and tourist offices. Finally, our last contribution is a set of **design principles for TEL authoring tools** and **guidelines to manage such research projects**, based on our experience.

As shown in *Figure* 4.1, I will pursue three main directions during my future research program. These will be presented in detail in the next section of this chapter.

In the short-term, I intend to **find more design principles for using game mechanics and HCI to encourage collaborative situated learning**. Actually, this work has already started with my last PhD student, Sebastian SIMON, currently in his third year of PhD.

In the medium-term, I will **continue my work with authoring tools**. First, I would like to pursue the MIXAP project at a European level. Second, I would also like to create a new authoring tool for using Virtual/Augmented Reality for training situations since this does not yet exist. Indeed, there is a great demand for such tool and Virtual/Augmented Reality headsets will soon become sophisticated and affordable enough to be used in school settings.

Finally, **in the long-term**, I would like to **pursue a wider challenge related to how research in TEL impacts the real world**. This will be done by proposing open-source software and collaborative architectures to encourage collaboration among researchers, Edtech (Education Technology) companies and teachers. Currently, there is a serious gap between our research projects and the use of technology in French schools. According to the traditional view of science, this is the way research works and the findings may take years or even decades to be used in everyday life (Roll-Hansen, 2009). But I believe that this gap must be substantially narrowed, particularly in my field of research, because of the applied nature of TEL and the rapid progress in technology. If we wait 10 years, not much will be left to use! I have started pursuing several directions to reduce this gap with my recent contacts at the Ministry of Education, notably efforts related to open source software and a shared national FORGE code repository. Finally, the access to our research papers and data also needs to be revolutionized since the situation with commercial publishers such as Elsevier and Springer has been slowly and surely deteriorating over the last decade. They have clearly found a very profitable system that they have no interest in changing, so the revolution needs to come from us. You will have to read the next part to find out more...

2 Research program

2.1 Short-term research program: tools and frameworks to foster collaborative learning

Many research projects, including TurtleTable(t) presented in the second chapter of this manuscript, have shown that computer-supported collaboration can positively impact learning (Dillenbourg, 1999). **Interactive tabletops**, in particular, are one of the technologies that have been proven to effectively encourage several learners to collaboration synchronously (Cress et al., 2021), (Mateescu et al., 2019). However, this type of equipment, and the collaborative applications designed for it, are rarely used in educational contexts. As the pilot teachers in the TurtleTable(t) project pointed out, they are too expensive (2 000 € and up) and bulky (weighing more than 80 kg) for use in the classroom. Given the investment, it also would be practical to be able to move these tabletops around not only within the school, but also outside for use during field trips for example. There are many occasions and locations that could potentially benefit from a collaborative learning tool. The objective of my fourth PhD student, Sebastian SIMON, is therefore to find a way to recreate the optimal collaboration conditions of interactive tabletops, but with a much more affordable, DIY (Do It Yourself) system. This is in line with our first research objective and, in particular, with finding new design principles to create collaborative TEL. It is also coherent with our second research objective, which is to increase TEL's acceptability and use in schools. In the two next sections, we will present our first results and perspectives. The first result is a technical alternative to interactive tabletops. The second result, more conceptual, is a framework to help researchers develop and compare collaborative learning environments.

2.1.1 SPART: on-Surface Positioning for Augmented RealiTy

Creating a tool to replace interactive tabletops is a major technical challenge because no such technology has yet been produced. One could use Augmented Reality, with smartphones or tablets, to display digital information on surfaces (such as traditional tables). However, classic, camera-based Augmented Reality technology is not ideal, especially for collaborative use. Firstly, if an image is augmented (e.g., a map of the world), the camera has to capture the whole image used as an Augmented Reality marker, which requires users to stand at a sufficient distance and hold the device appropriately. This is not feasible over a long period of time with large smartphones or tablets, due to muscle fatigue (Pereira et al., 2013). Holding the device (with two hands for children) also makes interactions with virtual or physical objects difficult. Another issue is its use within a group: if only one person is holding the device, the other group members have to huddle around this person to see the augmentations, and if each member of the group has their own device, they will not interact with each other.

With my PhD student, Sebastian SIMON, we therefore came up with a new configuration that should prevent these issues: **the mobile device is directly placed on the to-be-augmented surface** (e.g., map, image) and learners can **slide it on this surface** to see and interact with augmentations beyond the device's display. We call it ***SPART*** for on-Surface Positioning for Augmented RealiTy. As shown in *Figure* 4.2, this configuration is very similar to that of an interactive tabletop. It provides a common focal point for group attention and allows all group members to view augmentations, while maintaining awareness of other group members' actions and keeping hands free. Furthermore, the mobile device serves as a convenient input method, since its horizontal position on the surface allows for stability and is accessible from all angles. In addition, based on research on the ideal screen size to support collaboration, it seems likely that a tablet-sized display, combined with this sliding method, is superior to a tabletop, as the learner's gaze is only attracted to the device when used, whereas with a tabletop, the large screen size seems to attract the learner's gaze constantly, at the expense of a gaze directed at other members of the group (Zagermann et al., 2016).

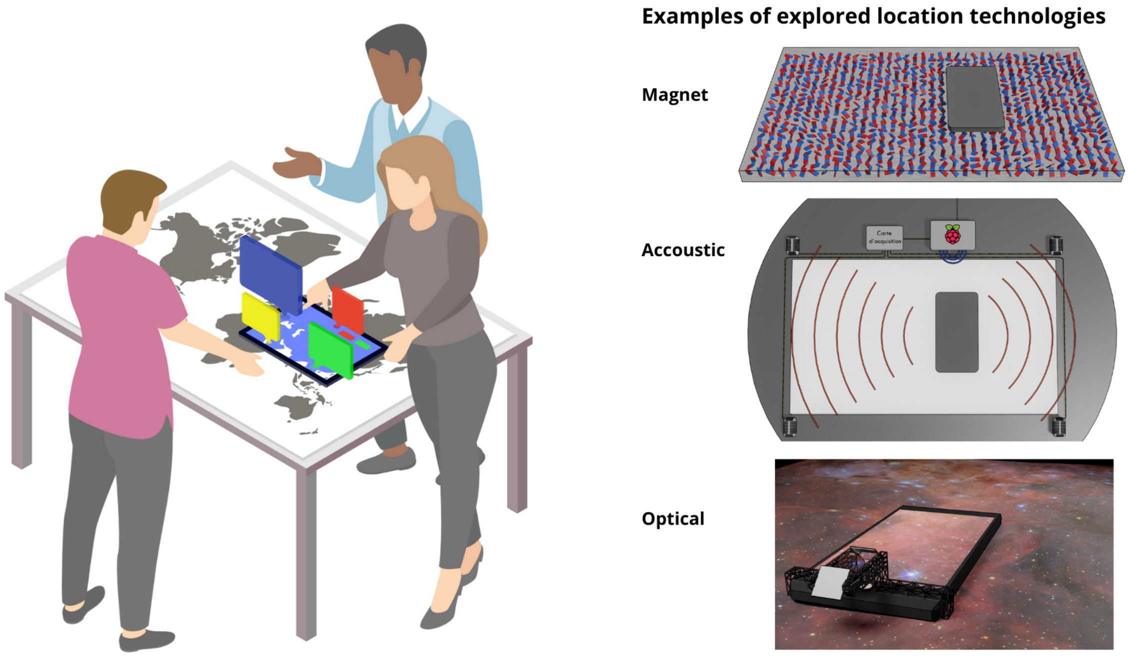


Figure 4.2: SPART: on-Surface Positioning for Augmented RealiTy

As depicted on the right of *Figure* 4.2, we explored several location methods that could be used to implement *SPART*, using external equipment and internal sensors available on mobile devices (e.g., magnetometer, accelerometer, camera, NFT reader, microphones) before producing one solution that costs less than 10 Euros and that fits in a pocket! As depicted in *Figure* 4.3, this prototype, called *SPART-Mem* (Mechanical and mobile) works with a string that is attached to the device with a small magnet. Sebastian SIMON developed a spring retraction mechanism that calculates the distance between *SPART* and the device, and a rotary encoder that provides the precise angle. These two values are sufficient to find the precise position of the device on an A2-size surface. A dozen other prototypes, with various localization techniques, and their evaluation according to criteria such as cost, precision and portability are detailed in two research articles that are currently in the review process.

A first version of *SPART* has already been tested with a class of middle school students, but more evaluations are necessary to evaluate its potential for supporting collaborative learning. *SPART* is actually a sub-project of the SituLearn project, so several experiments are planned outdoors, during field trips. The idea is to use *SPART* during or after the SituLearn scenarios so learners can view the information (photos, notes and audio recordings collected during the activities) directly on a shared map. The team's goal is to explain and analyze this data in order to collectively produce knowledge. For example, the first experiment is planned with students that need to identify trees by taking photos of their leaves, bark and other organs.

Figure 4.3: SPART-Mem (Mechanic and mobile)

After observing different trees, the learners then collectively analyze the photos and produce a botanical determination key with the help of *SPART*.

Furthermore, the prototypes have opened new perspectives such as a vertical version of *SPART* that can augment large wall-mounted maps. It can also be used as an input device, in conjunction with a video-projector, to create an affordable smartboard. Instead of springs, the device shown in *Figure* 4.4 uses weights to retract the strings with should reduce muscle fatigue and fear of breaking the device. We also thought of another version of *SPART*, with two rotary encoders, which would allow an object (e.g., hand, pen) to be precisely located in 3D space.

2.1.2 Collaborative learning framework

In parallel to the development of *SPART*, another of Sebastian SIMON's objectives is to come up with a framework for designing collaborative learning environments. One of the difficulties with research in collaborative TEL (also called CSCL for Computer-Supported Collaborative Learning), is the fact that researchers have developed a great number of tools, tested in various learning contexts and for a large variety of learning goals, without a common evaluation protocol or even common evaluation criteria to measure collaboration. In addition, the tools are evaluated as a whole, even though they are almost always composed of several collaboration functionalities (e.g., voting system, parallel input, shared and individual devices). In an attempt to clarify the situation and help researchers identify which collaboration functionalities seem most effective for a specific type of collaboration and learning context, we have carried out an extensive meta-analysis of 49 studies. This has allowed us to identify 20 tool functionalities and detail their potential impact on collaboration. The resulting map (*Figure* 4.5) is a first, tentative step towards a better understanding of the interplay between tools and collaboration (Simon et al.,

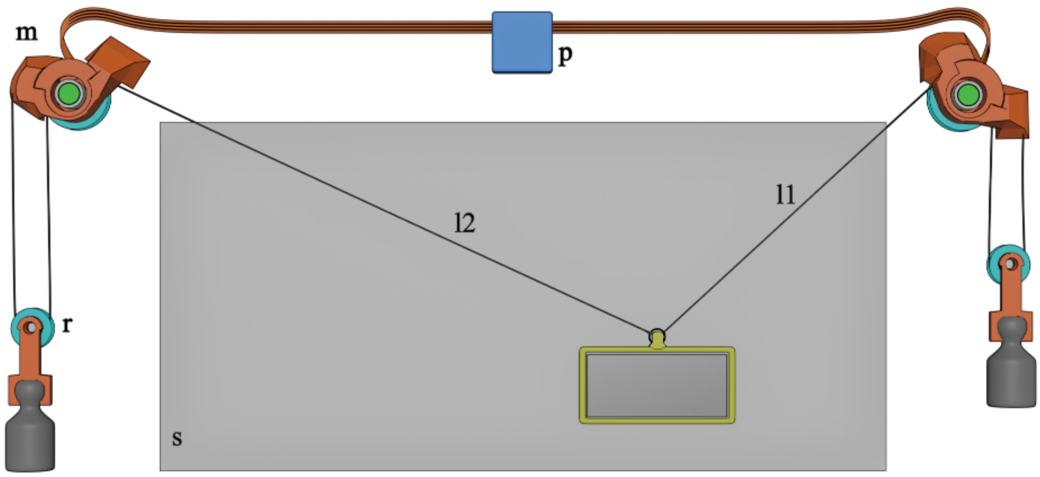


Figure 4.4: *SPART-ME Vertical*

2023).

The next objective is to provide a technical framework to help researchers implement and test these functionalities to compare them. The aim is to develop interoperable open source code blocs for each functionality that can be reused and combined. This will represent a gain of time for the research community, but it will also allow us to understand the collaboration mechanism better if we all have comparable and replicable scientific experiments. Since this is a colossal endeavor, the objective of my PhD student is to develop two or three of these blocs, at most, but he is already in contact with several other research laboratories of the CSCL community to pursue this long-term objective.

2.2 Medium-term research program: authoring tools to empower teachers

My second objective is to continue research related to authoring tools. In particular, I intend to continue the MIXAP project with European partners. We intend to write two proposals for an ERASMUS+ grant in March 2024. Another direction I would like to pursue is the creation of an authoring tool for Virtual/Augmented Reality training situations. Two projects have been initiated in this direction, one with another computer science laboratory and several French hospitals and another with a research laboratory in Canada.

2.2.1 Further investigation on Mixed Reality for education

In order to **continue research involving *MIXAP***, we are currently working on submitting an ERASMUS+ project, a European program to support education and training. This project will be led by researchers from the IMTEL group in Norway. They have been working on *MirageXR*, presented in chapter 3. This is a very rich open source Mixed Reality authoring tool with many functionalities (Fominykh et al., 2020),(WEKIT-ECS, 2023). *MirageXR* enables teachers to create complex learning scenarios that are location-based (unlike *MIXAP*, which creates simple activities on image-markers). The originality of *MirageXR* is the possibility for teachers to record “ghosts” of themselves to show important objects or do movements while they record audio explanations.

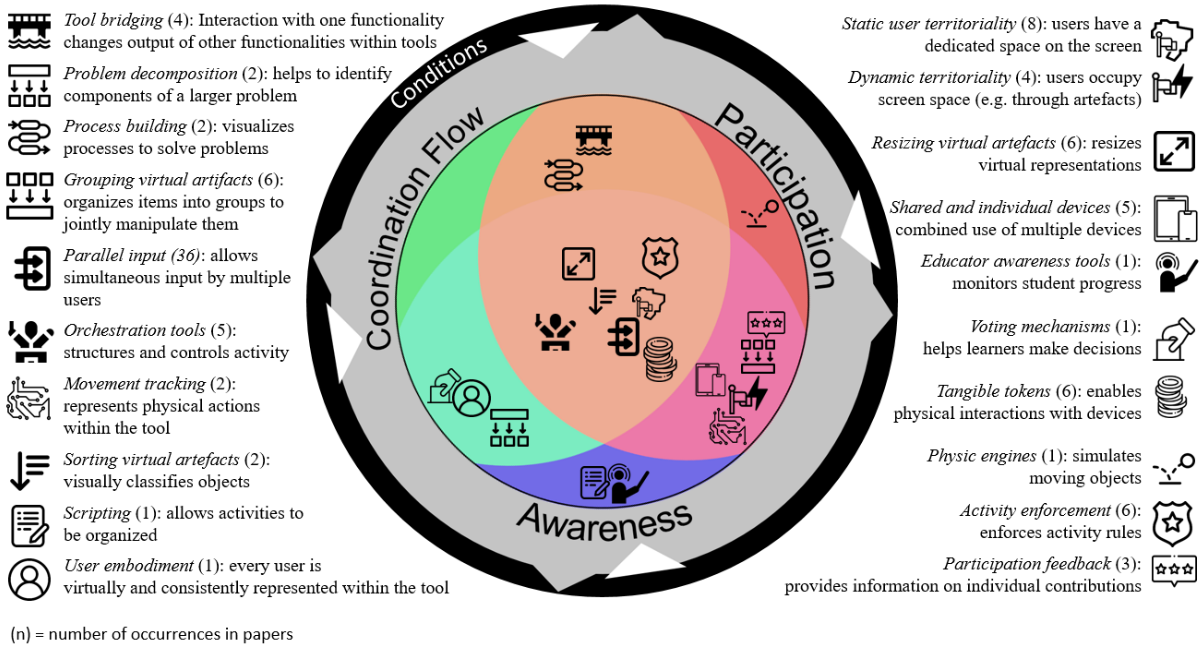


Figure 4.5: 20 collaboration functionalities and their impact on collaboration dimensions

MirageXR also allows teachers to add 3D AI conversational agents who can answer open questions. All these functionalities require very efficient tablets and high-speed internet. The second partners are from the International Hellenic University in Greece. They have designed *ARTutor*, a very simple AR authoring tool that only allows teachers to upload a PDF file of a book for example and place image augmentations on top of the images in this book (Terzopoulos et al., 2021). These two authoring tools are complementary to *MIXAP* since *MirageXR* is much more complex and better suited to professional training and *ARTutor* is, on the contrary, very simple and well adapted to augment only school books. *MIXAP* can be positioned between these two tools, since it offers several simple MR educational activities for books but also other educational materials (e.g., posters, cards, objects) (*Figure* 4.6). The objective of our ERASMUS+ project is to explore several transversal research questions to these three tools such as **How to design AR/MR authoring tools for education? How to integrate these tools in education? What functionalities should these tools offer? How do teachers actually use these tools? And how to train teachers to use them?** Our research contributions will therefore include new models of MR educational activities, methods to co-design authoring tools with teachers and teacher training methods to help them take full advantage of the tools. Studies on the impact of MR could also be done by comparing and finding similarities between the tools.

A second project idea is starting to form with researchers from the Technical University of Denmark and Bahcesehir University in Turkey. We currently have two research objectives. The first is to investigate **how to support the creation of a user community and the emergence of shared practices** around *MIXAP*. The tool will be deployed in several European countries to test out various strategies and tools to promote user communities. *MIXAP* will be hosted on the servers of La Digitale[1], a free and open source educational tool platform that is one of the main platforms used my teachers in France. The French Canopé network, and the

[1] https://ladigitale.dev/, consulted on the 5th of September 2023

Figure 4.6: Three complementary AR/MR authoring tools

equivalent organizations from the other countries, will also play an important role in the teacher training. Our research contributions will include communication strategies for this specific type of community management as well as platforms and functionalities built into the authoring tool to help teachers share their experience and MR activities. The second objective is to **explore the use of Artificial Intelligence (AI) as a means of assisting teachers** to design learning content. The use of AI, and especially generative AI, based on machine learning techniques, is exploding in TEL. AI is used for many different purposes, such as data mining for learning analytics, to create conversational agents who will help learners, to create learning content and even to grade (Chen et al., 2020). However, I agree with Tan (2020) that one needs to be very cautious about the use of AI when it comes to education because of the societal implications that it can have. As you have understood, the objective of my research is not to replace teachers but rather to empower them with tools they can use to improve their teaching methods. In this sense, I believe teachers could benefit from the use of AI to help them create learning content that they cannot create on their own or without a great deal of training and time. For example, AI could help teachers generate custom 3D models or images for *MIXAP* by entering a text prompt or another image. Systems such as *DALL.E2*[2] or *Midjourney*[3], that provide such functionalities, are already used in art education and have shown to enhance students' ideation process (Hutson and Cotroneo, 2023). One of the main difficulties with these systems remains prompt engineering (Liu and Chilton, 2022). Users need to master specific terminology, rules and syntax to get the desired type of image, much like computer programming. I have to admit I used *Midjourney* to generate the images for the four chapters of my manuscript. This helped me to find a style I liked and new ideas but, no matter how hard I tried, I was not able to get exactly what I wanted or a coherent style. I therefore worked with a graphic artist, who produced the final versions. Despite being a computer scientist, I guess I am better at communicating with humans. In order to reduce this difficulty, we could therefore offer prompt guidelines or a set of predefined styles to facilitate the use of such tools by teachers. AI could also be used as a scaffolding mechanism to automatically generate sample activities, based on activities created by other teachers and a few keywords. However, I believe AI needs to remain a complementary tool that is manually triggered by teachers and never one that is used automatically. It should also provide links to the resources it used to generate the content in order to help teachers understand where they come from. The fact that results of generative AI is difficult to explain is one of its major issues

[2] https://openai.com/dall-e-2/, consulted on the 5th of September 2023
[3] https://www.midjourney.com/, consulted on the 5th of September 2023

for education (Sun et al., 2022). Teachers should also have the possibility of saying they do not want their educational content processed by AI, just as they can decide to share their content with other teachers or not.

Finally, on a smaller scale, we also intend to propose a *Léa (Lieux d'Éducation Associés)* project built around the use of *MIXAP* in three local schools. This type of financing is provided by the French national institute of education (IFÉ) and the principles are the same as the School University Partnership projects presented in chapter 3. These projects aim at co-designing research objectives and hypotheses with teachers in order to find new teaching methods. This project would be led by my colleagues in Social Sciences. We intend to explore the various uses of Mixed Reality for education and its impact on teachers and learners. *MIXAP* could be just one of several tools used. A focus on children with difficulties could be explored since the selected schools are part of a priority education network and have several specialized classes that are interested in the tool.

2.2.2 Authoring tools for Virtual Reality

Similarly to Mixed Reality or ML applications for education, the large majority of Virtual Reality applications are custom designed for one educational setting and a set of educational goals. Companies who develop these have set up technical frameworks and libraries and sometimes even scenario editors to help them create this custom content in a more cost-effective way (Bouville et al., 2015). However, these tools are still intended to be used by professional developers and not teachers. In the TGRIS project, we started working on a very simple Virtual Reality authoring tool because teachers could add sentences to the simulation by editing a text file. This is very restrictive, but it still made a huge difference for the users and the acceptability of the tool. I intend to pursue this direction of Virtual Reality authoring tools in two projects.

The first project is called RACOON and is developed with anesthetists from Le Mans and Nantes hospitals, colleagues from the CREN educational science lab we worked with on *TGRIS*, and a computer science lab in Nantes that works on generating virtual patients, based on real data collected during procedures. Anesthetists currently use full-scale simulations with realistic manikins that are controlled, in real time, by a trainer (*Figure* 4.7). These simulations are custom designed and followed by several debriefing sessions in order to analyze the technical mistakes, but also to identify the coordination problems within the team. In our opinion, a digital tool cannot do better than these extremely realistic and custom-tailored simulations. However, they are very expensive and time consuming and practitioners only do them, at best, once every two years. My objective, in this project, is to work with CREN colleagues and medical practitioners to provide them with a simple, yet powerful authoring tool to create digital simulations that would be complementary to their current training. The research questions aim at identifying tools that could help anesthetists continue their professional training, in autonomy or with peers, between the full-scale manikin simulations. This could be done with lightweight simulations they could do on their phones or personal computers, but also with pervasive simulations they could work on, as a team, in the break room. Voting and game mechanics could be included to decide on the best action to take next. We also believe that, as for *TGRIS*, a Virtual Reality simulation could help practitioners not only prepare for being confronted with difficult situations, but also help them modify their relations with the nurses and other staff members that work in the operation room. We intend to change their point of view literally, by changing their position in the virtual environment. This project passed the first round of the ANR 2023 projects selection process, but not the second. We have therefore planned in improving the project description and resubmit it this year.

Figure 4.7: Anesthetist training with complementary tools and simulations

The second project is led in collaboration with the DOMUS lab in Sherbrook (Canada) and financed by VMWare. My objective in this project is to work, with a PhD student, on an authoring tool that will allow for the creation of custom learning activities based on object manipulation. The teachers will do part of the authoring while wearing MR smart glasses in order to train the system how to recognize the precise tools that are manipulated and the correct movements that should be done in order to use them. This system will use AI object tracking algorithms that have already been developed by DOMUS (Yaddaden et al., 2022) (*Figure* 4.8). We also intend to reuse and refine several models that have been developed in our lab, such as a descriptive model for designing multimodal feedback for gesture learning (Djadja et al., 2023b) and a model for gesture evaluation (Djadja et al., 2023a). These are currently used for the Evago project which provides a simulator for training dentists. Other models and scenario building methods are proposed in the Virtual3R project, a VR environment for training students before they operate on live lab mice (Oubahssi and Mahdi, 2021).

The new training tool proposed in this project will involve MR smart grasses. We intend to co-design and test it with teachers in Sherbrook and at Le Mans University working at a professional training center for non-destructive testing. This technique allows one to examine the structural solidity of an object (e.g., airplane, bridge, manufactured item) without invading its integrity (i.e., without cutting it to look inside). Non-destructive testing requires specialized training as it involves handling delicate equipment and subjective interpretation (Cartz, 1995). Our research contributions will include models and authoring tools that assist teachers in creating their scenario while they are wearing the glasses, models for new object recognition, models for movement evaluation and models for educational feedback, based on the comparison of the actions done by the learner and the expert teacher.

2.3 Long-term research program

My long-term goal is to facilitate the adoption of TEL in schools by bridging the gap between the TEL research community, schools and Edtech.

Currently, researchers in TEL are not really part of the Edtech and school ecosystem. Researchers sometimes work with pilot teachers to create and test their prototypes, but based on my 15 years of experience in the field, it appears that these prototypes are rarely used by more than 20 teachers. After the project has been completed, researchers usually simply give free access

Figure 4.8: Non-destructive testing training system with smart glasses

to their prototype online or put it on an app store. At best, they write a few posts on social media to encourage other teachers to use it, but that is it. As explained in chapter 3, research laboratories are just not equipped to do more. Their skills and the funding they get exclusively cover their research objectives, and the final quantifiable result is expressed in number of scientific articles published. The prototypes are merely side products of research and nothing encourages researchers to maintain them or transform them into robust tools that could be used by teachers. Most prototypes therefore end up in the drawer of a dusty server and become obsolete at the following major update of one of the technologies or libraries they depend on. If the prototype is developed as a web technology or a mobile application, this can happen in just a few months! To sum up the situation: these prototypes, co-designed with teachers, and for which the educational value has been scientifically proven with several experiments, simply die away without any immediate benefit for society or the pilot teachers who participated in the project. What a waste!

On the other end, in the "field", teachers are submerged by digital tools provided by Edtech companies. These companies strike deals with representatives of the Ministry of Education at various levels. For example, a deal can be made with one or all rectors, each one representing an entire regional education authority (18 in all France) or, on a smaller scale, with regions, departments, cities or schools. The production and maintenance of educational digital tools in France are increasingly delegated to private Edtech companies. After the COVID pandemic, the government set up the apps.education[4] centralized platform, with basic tools to facilitate class organization such as video conferencing, file storage on a cloud and collaborative note taking. However, the maintenance of TEL applications that provide learning content and activities was decentralized to the regional level (académies) or handed to the national Canopé teacher training network and both of these tend to, in turn, outsource the responsibility to Edtech companies. The access to TEL tools is therefore very inequitable from one area to another and absolutely not sustainable, since the deals only last for several years (maximum five). Teachers therefore regularly lose the educational activities and content they create or put on these tools, because those responsible for the tools have no obligation to make them compatible with each other or with a given format. In addition, because the market is very competitive, Edtech companies seem to massively invest in communication, branding and lobbying and rarely have the means to analyze the use of their tools with scientific standards. Some Edtech companies, such as Lalilo, still invest a lot of time in UX design to create simple and useful tools with the help of teachers. Nevertheless, the lack of long-term vision and quality of service that characterizes the majority

[4] https://projet.apps.education.fr/, consulted on the 5th of September 2023

of Edtech companies incites teachers to use TEL tools found on Internet, which at least provide some free content and functionalities. However, teachers have no guarantee that these tools will not become paying or simply be shut down, possibly the very next day. This is what happened, for example, with Aurasma, a free Augmented Reality authoring tool that was used by thousands of teachers in France and that suddenly disappeared without warning.

With this situation, how can teachers have enough faith in digital tools to spend their precious time understanding how they work and creating new content with them? As a matter of fact, it is a wonder researchers still manage to recruit pilot teachers. After all, from their point of view, we want to create yet another digital tool for which we cannot even guarantee its robustness or its sustainability after the end of the research project (at best three years)! Why should they help us out for free?

Of course, the situation is not all that sinister and researchers do, on rare occasions, work with Edtech companies. For example CIFRE research contracts, co-financed by the government, allow PhD students to work in a laboratory and a private company at the same time. Research projects financed by the French national research agency (ANR) can also be led with a private company as a partner, but this is far from being mainstream. Researchers also work with teachers and schools. Usually this is done at a very small scale, by contacting local teachers. But some specific project funding organizations, such as GTNum, Léa or E-FRAN, also encourage collaboration with several schools or entire regional education districts but, to be honest, these types of projects require a large amount of work for a very limited budget, which is not very motivating for researchers. Larger funding programs, such as PIA, also exists but for mature projects that involve entire education regions and a large number of researchers and companies. The current situation generates a huge waste of good-quality, original TEL applications developed by researchers. These applications could be taken over by Edtech companies, who have the infrastructure to make them more robust, improve their design and functionalities and provide a minimal support service for teachers that need help using them. This would benefit the Edtech companies because they would be able to use the scientific results to promote the tool, and it would also be a great opportunity for researchers to test their tools with a larger panel of teachers. These long-term experiments with hundreds of teachers are very rare in TEL and yet, they provide much more information than the one-hour experiments we usually manage to set up. I have described the situation in France, but it is similar in other European countries. The situation in North America and Canada seems slightly better since research labs invest a great deal in communication and in finding private funding or donations. The schools are also better equipped in tablets, computers and Wi-Fi and teachers are in the habit of using digital tools.

As depicted in *Figure* 4.9, the ideal life-cycle for TEL research is to continue beyond the first phase, carried out with pilot teachers. The pilot prototype could be transferred to an Edtech partner company, capable of transforming it into a stable application and providing all the packaging and support services, such as professional tutorials for teachers. The project could then undergo a second phase of Design-Based Research, but with a much larger selection of teachers and over a longer period. This "scaling up" process could, of course, be another, larger research project and other spin-off projects could be created after that to test variations of new tool functionalities.

However, as we have noticed with the SituLearn and the MIXAP projects, there are several dynamics at stake that make it very challenging to find an Edtech partner, especially when you have ethical principles about what public research should be. My utopian vision is that public research should be for the greater good of humanity. In more practical terms, I believe the

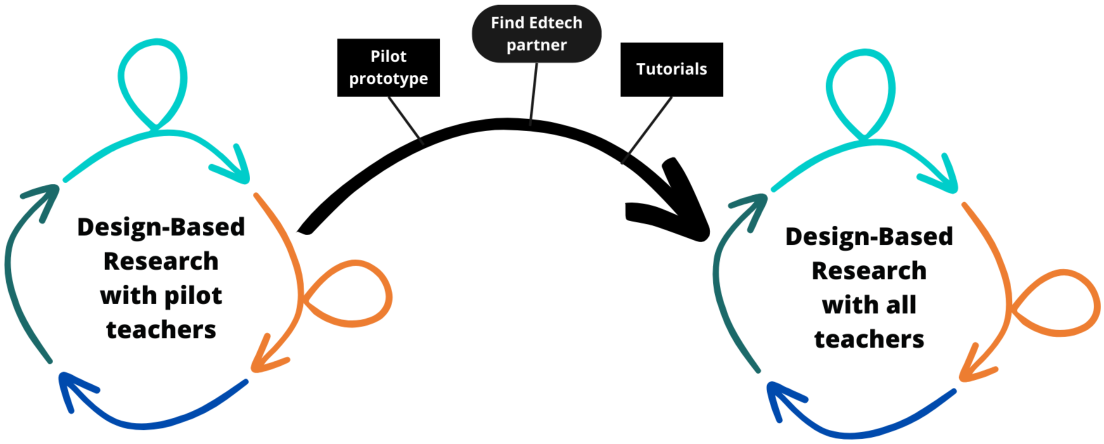


Figure 4.9: Optimal life-cycle of a TEL research project

articles we write and the tools we produce should be **accessible to all, for free**. After all, our research is paid for with public taxes so it makes sense to give back the products of our research to the people. However, maintaining digital tools and support services costs money and Edtech companies need to make a living.

The first solution is to find an alternative economic model that will ensure teachers can access the main functionalities of the tool, but that still guarantees enough income for the company. This can be done by selling additional functionalities, content or teacher training sessions. If it is possible, the company could also make a living by selling the tool to professionals in other sectors. The second solution is to find external funding from regional education authorities, cities or schools who would be willing to pay a subscription. This solution is financially more advantageous for Edtech companies but requires a non-negligible investment on their part to make sure teachers can create an account on their tool, with the national GAR authentication system. However, both of these solutions are very hard to set up because they rely on the researcher's capacity to be very convincing about their tool and its benefits, even though they do not have the means to carry out a proper communication campaign or the network to find potential financiers. In addition, these solutions are not completely satisfactory because none of them guarantees the tool's sustainability and, depending on the source of financing, the tool could only be accessible to a small selection of teachers for whom the subscription was paid. The situation is very complex. In the next sections, we present an alternative organization that could be a game changer, but that is still at its premises.

2.3.1 Open source software: the way to sustainable TEL systems?

Open source software is software that is released under a license which **grants users the rights to use, study, change, and distribute the software and its source code** to anyone and for any purpose without any fee (Laurent, 2004). Some prominent examples of open source software include *GNU/Linux*, *Firefox*, *Moodle*, *WordPress*, *OpenStreetMap*, *MySQL* and *VLC media player*. There are many different types and licenses such as MIT License, the GNU General Public License (GPL) and the GNU Lesser General Public License (LGPL) (Sen et al., 2008).

Before we continue, it is important to point out the fact that the term "open source" has known several interpretations and philosophies in its history. In the beginning of computer science, all software was open source. Then, companies realized they could make money by selling the code. At that point, offering open source software became a philosophical stance to keep software open. In 1998, the Open Source Initiative (OSI) proposed a definition of the term (Initiative, 2007). This initiative was carried forward by companies who wanted to make this term their own again. They viewed open source software as beneficial for companies, because their codes could be improved by users, for free. In order to counterbalance this profit-centered vision, the American activist Richard Stallman started using the term **Libre software** (yes, in French). He likes describing his philosophy as *'Liberté, Egalité, Fraternité'* (the motto of the French republic) to show that the objective is to give the power back to the people, and that we should be able to do what we want with the software we use. You can probably see, from my research work, that I can relate more to this last philosophy. However, the fundamental rights, listed at the beginning of this section, remain the same and the term "open source" is used in all the documents related to open science so I will continue using it in this manuscript. By the way, if you are running out of documentary films to watch, I strongly recommend *'LOL – Logiciel Libre une affaire sérieuse'*[5], that explains the history of open source software.

It is also important to distinguish "open source" from "free" software. The two do not necessarily go together. For example, quite a few TEL systems are free but are not open source, meaning that you cannot have access to the code or modify it. On the other hand, it is possible to download the code of open source software for free but, for certain types of software to work, you need to set up servers and data bases. These services are not included in the free code and therefore require some technical setting-up to be done on your servers or paying a company to do this for you.

Open source offers several advantages for TEL research. First of all, the users are treated like co-developers and are encouraged to submit new functionalities, code fixes, bug reports and documentation. This is completely in line with the Design-Based Research method that implicated the teachers in the design process. Secondly, because it can implicate a large community of developers and testers, open source helps produce reliable, high-quality software quickly and inexpensively (Reynolds and Wyatt, 2011). Finally, and this is very important in our case, open source makes it possible to produce sustainable software. Indeed, the software is not dependent on the company or author that originally created it. Even if the company collapses or, in our case, the researchers go on to another project, the code can continue to exist and be developed by its users. Also, open source uses open standards accessible to everyone. Thus, it facilitates interoperability between software. This is essential when it comes to TEL, because this means teachers do not have to lose all their content when they switch from one software to another. However, interoperability is complex and progress still needs to be made toward finding simplified open standards and pivot formats (Almeida et al., 2011). In France, promoting open source software is officially one of the main axes of the digital strategy of the Ministry of Education for the next five years (MENJ, 2023) even though the conviction with which this strategy is enforced depends on the Minister of Education and his/her counselor, and these political figures typically change very often. For example, the last minister, Pap Ndaiye, only stayed for a year.

However, **open source does have a few disadvantages**. First of all, from the researcher's perspective, it limits the choice of libraries and software they can use because open source software

[5] https://www.imagotv.fr/documentaires/lol-logiciel-libre-une-affaire-serieuse, consulted on the 5th of September 2023

needs to be completely open source, all the way through. This forces researchers to double check the licenses of the bits of code they are using and sometimes give up on proprietary libraries that would sometimes be better suited to their needs. Another drawback is the fact that open source code is also made to be read by other developers, and extra effort is therefore required to make it well organized, clean and documented. Let us be honest, this is clearly not the priority for researchers, who are usually trying to finish the prototype in time for the next experiment. In addition, the effort might not be worth it for all research projects. For short-term exploratory projects, with minimal funding, hiring interns to develop one-shot proof of concepts (PoCs) might be a better alternative. However, for long-term projects, this initial effort of creating good-quality documented open source code is beneficial for everyone because it can be reused for other projects and even by other researchers. For example, *MirageXR*, cited earlier in this chapter, is an open source tool that has been continually improved through several European projects. This ideally requires having a long-term research engineer who understands the code and can maintain it throughout the projects, and this is not often the case in French labs. Open source projects also work best if there is a large community of users willing to make the effort of providing feedback and funding to maintain the tool and help it evolve. This requires setting up community management and communication strategies.

However, **the main difficulty with open source is to convince Edtech companies**. As we have noticed when approaching companies for *SituLearn* and *MIXAP*, this concept threatens their usual economic model that is based on proprietary software. In 2001, Microsoft executive Jim Allchin publicly stated that "open source is an intellectual property destroyer. I can't imagine something that could be worse than this for the software business and the intellectual-property business." (Charny, 2001). Yet, companies could very well benefit from maintaining and improving open source software, as well as selling their support services, and mentalities are slowly changing. For example, in 2010, Microsoft's CEO, Satya Nadella, announced that now "Microsoft loved Linux" and, Microsoft has since initiated several open source projects (Microsoft Windows Server Team, 2015). A shift in mentality is taking place, but the entire Edtech market still needs to evolve in order to give companies enough financial incentives to change their habits. In the next part, we present a setup that could encourage them to adopt the open source philosophy.

2.3.2 Forges: this is the way

In 2023, Alexis Kauffmann, the head of the digital department of the Ministry of Education, set up a sovereign open source code repository called the FORGE[6]. Currently, this forge, which is managed by the AEIF (association of computer science teachers in France), is presented as a place for computer science teachers to deposit and share code, but I believe it could be the keystone of an ecosystem favorable for researchers, Edtech companies and teachers from all disciplines. Actually, there are many other forges that coexist. Researchers, for example, use forges that are often restricted to one laboratory or the commercial *Github*[7] repository that they connect to with their name, without identifying their affiliation to a lab (Berre et al., 2023). The ministry's sub-management branch, called SOCLE, also manages a forge with all the important tools of *apps.education*. This forge is quite different from the FORGE presented in the beginning because it integrates several tools for test and quality control and is intended for large scale, professional deployment. This national forge is managed by the educational district of Brittany, but all the

[6] `https://forge.aeif.fr/`, consulted on the 5th of September 2023
[7] `https://github.com/`, consulted on the 5th of September 2023

education districts, teacher training networks and associations financed by the government also have their own forges. Rather than one forge, it is more accurate to picture a group of forges that have various functionalities and purposes. Even if this is not yet the case, these forges could be federated. Several recent projects[8] have shown this is possible. For example, the FORGE, managed by the AEIF, could allow its users to contribute directly to the forge of a research lab or that of an Edtech company, and vice versa. As is the case for Fediverse (a federation of open source social media tools) (La Cava et al., 2021), this should overcome the obstacles preventing several categories of users, such as researchers, people working for Edtech companies and teachers, from working together (no authentication problems, no moderation problems).

As depicted in *Figure* 4.10, **this federation of forges**, could create a favorable ecosystem between researchers, Edtech companies and teachers. It offers functionalities to deposit code but also to **manage and federate a community of users and contributors** (not necessarily only teachers, researchers and Edtech companies). In *Figure* 4.10, this is pictured as people following Komit[9], the beaver mascot we proposed for the FORGE. Researchers and teachers could **co-design** good quality, innovative TEL system prototypes with teachers which would be deposited in a forge. These prototypes could then be **up-scaled to professional robust tools** by Edtech companies who have the skills to maintain TEL systems and provide support services. They could also add improvements that would benefit to all, because the updated source code would be uploaded back on the open-source forge. The Edtech companies play an important role in this ecosystem as they ensure maximum **appropriation** of these systems by improving the UX design and teacher's acceptability. Let us present the point of view of each of the actors.

TEL researchers can benefit from the help of Canopé, DAN (the digital service of the regional education authority) and the teacher training INSPE schools to get in contact with pilot teachers. Once the project is mature enough, they deposit the open source code for their prototypes on one of the forges. They could also take code from a forge to improve or build on other TEL systems.

Teachers, or the school's IT department, could access these applications and install private instances on their servers. This could also be done by digital experts that are nominated, among the teachers, at various levels (ERUN, IAN). Teachers could innovate and provide feedback on these applications by posting comments and bug reports on the forges and maybe even ideas on how to use these applications. If they have computer programming skills, they can also modify the code and deposit this new version on the forge as a new branch. If the community of developers and users believe this new version is a valid improvement on the former version, it would be merged with the main branch as the official latest version. But let's face it, teachers and school IT departments rarely have time to develop code. This is when the Edtech companies come into the picture.

Edtech companies could be mandated by schools to install and maintain a TEL application taken from a forge and provide support services for teachers. With this new setup around an open-source forge federation, teachers would be certain to have a sustainable application with their educational content (even if the company changes). Ideally, the contract should be signed by the Ministry of Education so that all teachers could benefit from these services and not just those in wealthy schools and regions. Financing sources for this already exist, such as Edu-up[10], which

[8] `https://gitlab.com/gitlab-org/gitlab/-/issues/6468` and `https://codeberg.org/forgejo/forgejo/issues/59`, consulted on the 5th of September 2023

[9] Komit refers to the git commit –a command used in forges to saves modifications made in a file

[10] `https://eduscol.education.fr/1603/le-dispositif-edu`, consulted on the 5th of September 2023

encourages open source projects. The companies could also be asked to modify the applications by adding extra functionalities, for example. In this case, they would be required to put the updated source code back in the forge so that everyone can benefit from it, including teachers and researchers.

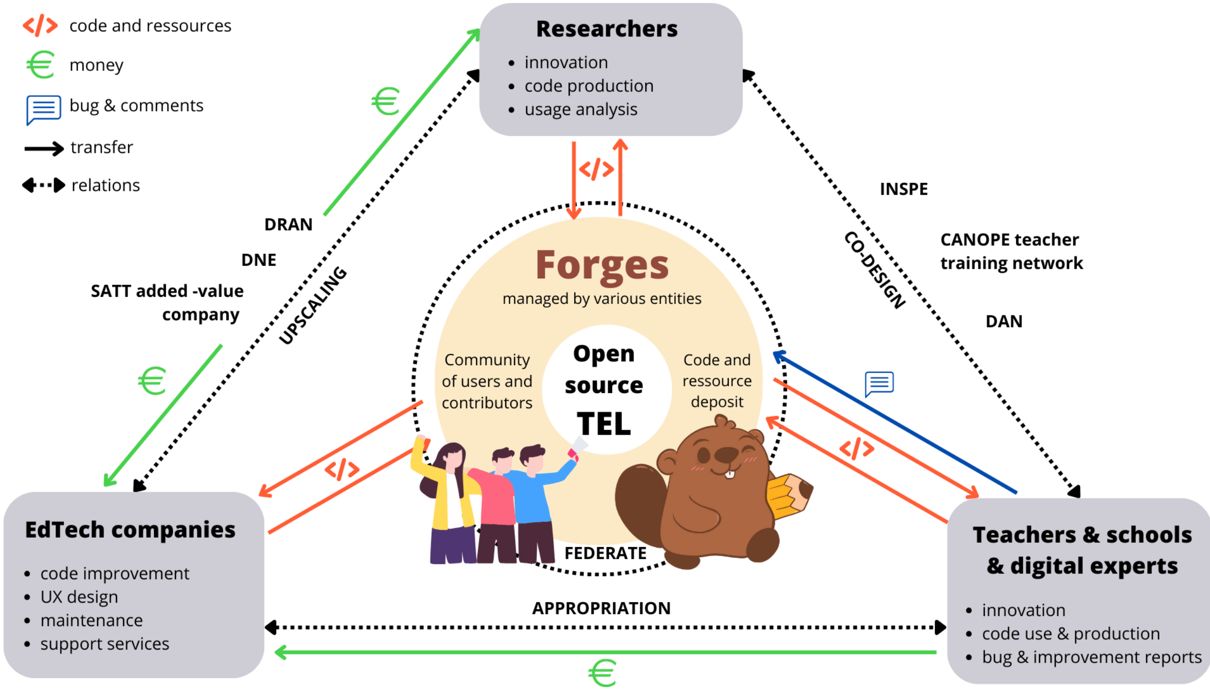


Figure 4.10: A federation of forges to unite researchers, Edtech companies and teachers

The choice of the TEL systems to be financed is delicate. The teacher training centers, such as INSPE, Canopé or EAFC, would be ideal agents for promoting new TEL systems that have been co-designed by teachers and have proven satisfactory. The local and regional digital experts could also report the most useful TEL systems to the ministry. But this method will never allow teachers who have a specific need to be satisfied. A more direct solution is therefore needed. A system of resource checkbook was recently announced, on the 4th of July 2023, during the national digital strategy seminar. The objective is to provide each teacher with 200 Euros per year to buy digital resources or services. This could be used to have access to an Edtech tool, install an application on the local school server or even finance an upgrade of the tool. Even though this system seems ideal, it will be important to carefully design the catalogue from which the teachers will be able to select the TEL tools and resources. Open source systems should be recommended or at least clearly identified so that teachers know that, by financing these systems, they are contributing to the production and maintenance of long-lasting, good-quality tools for the entire community. The national and local representatives of the Ministry of Education (DAN and DNE) already finance the upscaling of research prototypes by funding projects. However, this financing should clearly require that the TEL systems produced be open source, in order to ensure the Ministry is contributing to the creation of long-lasting software and not just financing private companies. Hugues LABARTHE, one partner from our education district, who participated in such a project, called CNEC (Carnet numérique de l'Elève Chercheur) and financed by PIA3 grant (E-FRAN project), was very frustrated not to be able to use the resources and TEL tools produced during the project. According to him, one of the reasons is the fact that they did not manage to agree on open source productions and the economic model with the Edtech partners from the beginning of the project. Finally, the last source of financing, that could encourage Edtech companies to embrace open source, would come from the SATT societies. These societies are financed by the French government to help transfer the results of research to society by putting researchers in contact with companies and depositing patents, for example. They could therefore pay Edtech companies to improve TEL prototypes, created by researchers, to enhance their chances of being used by the community. This was the case for SituLearn and MIXAP. The SATT societies can then reimburse this initial investment by making companies pay for software licenses or royalties and the surplus goes back to the researchers.

This reflection is still at its premises and a lot still needs to be done to create this ecosystem. In March 2023, I organized the LIUM Edtech Day[11], with workshops in the morning and conferences, demos and a round table in the afternoon to initiate reflection on this topic. This event brought together more than a hundred teachers, researchers, Edtech companies and representatives of the Ministry of Educational at the local and national level. The reflection initiated during the round table of the conference was continued during a workshop on open source TEL[12]. This workshop was organized by colleagues at the national TEL conference in June 2023 (EIAH 2023). The discussions held during these events highlighted two main research axes that can be pursued in parallel.

The first axis is quite political. It aims at **federating the TEL community around several forges**, which also implies improving our communication with schools and Edtech companies that are simply not aware of our existence. Of course, there are some local initiatives, such as the conferences organized by Élise LAVOUÉ in Lyon, which aim to inform teachers and representatives of the regional education authority of the latest scientific projects and findings. To my knowledge, three such conferences have been organized in 2019, 2021 and 2022 on specific topics (Moodle and gamification) with workshops and round tables. But this should be done by all the TEL labs in France, in all regions. In addition, researchers are very rarely present at the main Edtech events such as Ludovia[13], Educ@tech[14] or the Learning show[15].

The second axis aims at answering various research questions related to computer science, educational science and information science. **How can teachers be more implicated in the lifecycle process of TEL?** In particular, can we provide design models and authoring tools to help teachers customize TEL tools to their needs and share these new versions with other teachers (Marne, 2014)? The idea is to support a meta-design process in which teachers play a central role throughout the design process and evolution of the TEL tool (Fischer et al., 2004). The objective is to rethink the interface of software forges to encourage all teachers to contribute, and not just teachers who know how to program. These questions are part our project that was very recently accepted and my next PhD student's subject.

2.4 Very long-term research program and vision of research

If you have made it this far in this manuscript, you now know my research program for the next few years. However, I have an even crazier, long-term vision for research that I want to share

[11] https://lium.univ-lemans.fr/en/journee-\gls{Edtech}/, consulted on the 5th of September 2023
[12] https://lium.univ-lemans.fr/atelier-logiciels-libres/, consulted on the 5th of September 2023
[13] https://www.ludovia.fr/, consulted on the 5th of September 2023
[14] https://www.educatech-expo.com/, consulted on the 5th of September 2023
[15] https://www.learning-show.com/, consulted on the 5th of September 2023

with you. It has to do with Open Science and the fact that we have to take control of our own destiny if we want to change the way things are done. This is a bit political and controversial, so feel free to stop reading at any time.

Open Science is a set of recommendations aimed at "making science more accessible, inclusive and equitable for the benefit of all" (Director-General, 2022). It was defined by UNESCO in 2021 as an inclusive construct that combines various movements and practices. Among them, Open Science advocates the **importance of 'opening up' three types of scientific production**:

- Source software
- Educational resources and data (reports, presentations and data sets)
- Publications (peer-reviewed journal articles, books, reports, conference proceedings)

Even if this is not yet the norm in France, it will probably be in a few years, since research projects funded by Europe and the National Research Agency (ANR) must all comply with these recommendations. Let us analyze how things are evolving in terms of access for these three types of scientific productions.

2.4.1 Open software and source code

Open Science clearly advocates the production of **open source software**. This is very much in line with my long-term research perspectives outlined above. Although this is not yet common practice in the TEL community, I am confident that it will develop in the next few years because of its benefits for education and research.

2.4.2 Open Educational Resources and Open data

Open Science **promotes the production of Open Educational Resources (OER) and research data**. This movement aims to reduce barriers to access and is often motivated by a desire to provide an alternative or improve educational paradigm (Peters, 2008). Such resources are typically licensed under Creative Commons which can be configured to allow various degrees of freedom such as adaptation, translation, remix, reuse and redistribution. This type of license can be used for many types of educational resources, such as texts, worksheets or illustrations. I encourage teachers participating in my Ludifik'action professional training course to publish their game materials and rules under a Creative Common license.

Open Educational Resources can be shared online, on websites, specialized forums, and even on the FORGE. A small, yet very active, community of teachers share their exercises and course plans on this forge although it is initially intended for software. It gives them good visibility and they can use the functionalities of versioning, commenting and collaborative editing that are offered on a software forge. This is a phenomenon we want to analyze with our future PhD student and in our GTNum project.

Furthermore, the producing of Open Educational Resources and data involves the **use of open source software**. In fact, one of the guidelines states that educational resources should be released under an open license that allows free access, use, adaptation and redistribution by others with limited or no restrictions (UNESCO, 2019) and that research data should be made available in accordance with the FAIR principles (Findable, Accessible, Interoperable, and Reusable) principles. To be clear, this means that educational content and data should not be made available in a proprietary format such as doc, xls or ppt. As civil servants of the French government, we are not even legally allowed to use these formats (JORF, 2016)! As you can see, we are far from complying with this law...

One of the reasons for this is the powerful Microsoft lobby which manages to strike deals with schools and universities. Students get used to this software and continue to use it in their jobs. Personally, I have been addicted to the *Microsoft Office* suite since my undergraduate days, and it is very difficult to break the habit. Fortunately, there are many alternatives, such as *Libre Office*, which creates ODT format in an open format, and the functionalities offered are now almost equivalent to Word. Latex, of course, is widely used by scientists, but it is not easy to read. An alternative to Latex is the Markdown language. If offers two advantages: it is easier to read, and it can be automatically transformed into a web page or even other types of documents such as PDF and EPUB format (Balsch, 2018) thanks to editors such as *Zttlr*[16]. This makes it easy to publish reports, articles, or even entire PhDs in the most appropriate format. The point is this: we are not yet there, but the situation seems to be moving in the right direction.

2.4.3 Open Access to Publications

The only item on the list that does not seem to be going in the right direction is open access to publications. Let me explain why. The concept of "open access publications" has been twisted by publishers into a masterpiece of marketing. I have to admit that they have been very clever! If you are not aware of the problem, I suggest you watch William E. Flanary's excellent video[17]. He is an American comedian and ophthalmologist who performs under the stage name Dr. Glaucomflecken. But, since YouTube is infested with advertising and you never know when it will be bought by some crazy billionaire and shut down (this is what is happening to Twitter), I created a more permanent trace of this video by turning it into a text message dialog (*Figure* 4.11). Please take a minute to read it or watch the video.

Commercial publishers have turned this beautiful philosophy of open access into a very profitable extortion machine. They now charge ridiculously high article processing or publication fees. In TEL research, they do not charge as much as the 11 000 dollars charged by Nature, but several journals ask for 2 000 euros for open access!

Actually, there are a number of variants of open access types: gold, green, hybrid, bronze, platinum, and black (marketing). Different publishers may use one or more of these options, although the most common ones are gold and green. **Gold open access** is free for readers and paid for by the author. The publication fee may also be paid by their institution or country. For example, Switzerland has signed a contract to ensure that all papers from Swiss laboratories will be published in gold open access by Frontiers (Communications, 2022). The University of California also signed a gold open access agreement with one of the five multinational scientific publishers, Springer-Nature (Kwon, 2020). Papers published in gold open access are subject to the traditional peer-review process. **Green open access** is free for both the reader and the author, but does not necessarily go through a peer-review process. Authors can deposit the accepted paper or a nearly-final paper, so there is no guarantee of scientific quality. For comparison, the

[16] `https://www.zettlr.com/`, consulted on the 5th of September 2023
[17] `https://www.youtube.com/watch?v=8F9gzQz1Pms`, consulted on the 5th of September 2023

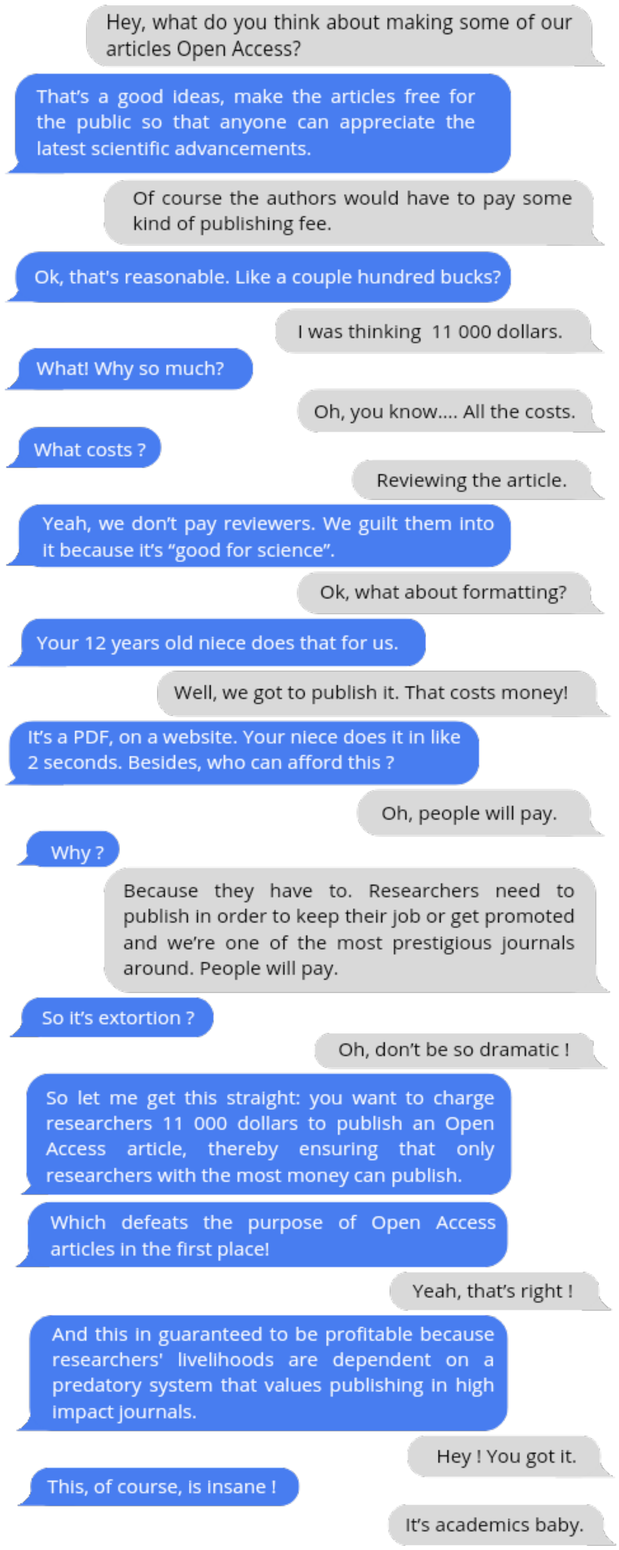


Figure 4.11: Dialogue based on Flanary's video 'Academic Journals Doing Crime'

classic publishing model is paid for by the readers, free for the author, and the papers go through a peer-review process.

Paying for gold open access is only possible for the wealthiest universities and laboratories. Remember that this cost is in addition to the high fee that universities already pay for having access to the other papers in the journal that are not “gold”. Some universities in France have joined forces (Couperin open-edition agreement[18]) to reduce these costs, but they are still very substantial. Elsevier’s profit margin last year was 37.8%. Compare that with Google (21.2%) or Apple (24.56%) or even Shell (10.95%). These commercial publishers are not on our side, they are not our allies and they do not care about research or education.

Fortunatly, there are some loopholes. These commercial publishers do not own the content of the paper. They only own the format of the file (font, size, header, footer of the document), so researchers are legally allowed to put their “final draft” papers (the same content that was accepted by the publisher, but with a different format) online (on their personal web site, for example). In France, HAL[19] is the official repository that all researchers should use for the metadata description of their papers and the document (final draft). This is free of charge for authors and readers. In our lab, all researchers are strongly encouraged to this, but we are very far ahead compared to others. Colleagues I have worked with in the social sciences, for example, were clearly against it. They agreed to post the metadata description, but not the document, saying that it was not compatible with the contract they had signed with their publishers, and they were afraid they would be banned from publishing if this was discovered. In fact, publishers exploit the ambiguity of the term “publication” in the contract. By law, the authors are the exclusive owners of the content (i.e., text, figures) of the publication, and they can deposit the final draft wherever they want. The PDF that is created by the publisher (with the correct format and style of the journal or conference proceedings) is the property of the publisher, but can still be placed on HAL, by law, after an embargo period (6 months for computer science publications and 12 months for social sciences and humanities publications) (Légifrance, 2016).

However, even if the paper is available for free on HAL, the publisher’s website will almost certainly appear first when searching on Google, the most popular search engine (85% of the search market share[20]). This is because publishers pay a high price to be well referenced by Google, making the random web surfer think they have to pay 42 euros to see our article. This is not really in the spirit of making science more accessible. Sci-Hub is another loophole, used intensively by more than a quarter of young researchers worldwide and an even higher proportion in France (Nicholas et al., 2019). Even though it is illegal, users do not see the problem because they say it improves access to scientific knowledge.

Let’s face it: the situation is insane (I’m just quoting William E. Flanary) and we are the only ones in a position to do anything about it. Having a publisher is not as obvious as it used to be. Before, they produced hardcover versions of the proceedings, which required professional printing equipment, but now they just put together a PDF file. We are already do most of the work: writing the papers, putting them in the right format, reviewing the papers, and overseeing the whole publication process.

Mainly, publishers have only two services left to offer. The first is proofreading which is

[18] `https://www.couperin.org/negociations/accords-specifiques-so/open-edition/`, consulted on the 5th of September 2023

[19] `https://hal.science/`, consulted on the 5th of September 2023

[20] `https://gs.statcounter.com/search-engine-market-share/desktop/worldwide`, consulted on the 5th of September 2023

very time-consuming and cannot be done by reviewers who need to focus on the content of the paper and not the format. However, in my experience, the quality of proofreading varies from publisher to publisher, from very thorough to non-existent and this proofreading could be done by scientific volunteers, as it is done by members of the editorial committee for the STICEF journal[21]. The second service publishers can offer is communication and lobbying to increase the prestige of the journal or conference to attract more submissions. Over time, as the number of submissions increases, the acceptance rate can decrease, thereby increasing the quality of the publication. This is more difficult to do on our own, because building a reputation takes time. One of the main tools to measure the quality of publications is their presence in Scopus[22] and DBLP[23] and their ranking in SCIMAGO[24] for journals or CORE[25] for conferences. Together with the board members of the Serious Game Society, we have been trying, for several years, to include the IJSG journal and the GALA conference proceedings in these ranking systems, but it is very difficult. All the A-ranked journals and conferences are very old and managed by the major historical commercial publishers (e.g. Elsevier, Springer).

Dethroning them will require a massive team effort within the community. We must collectively decide to stop reviewing papers for these publishers and promote our own open access and free journals and conferences. But I am perfectly realistic. I know that this is a very long-term project because it takes time to revolutionize a well established system, and it can only be done by researchers who feel they have a secure position and are not chasing publications to build their CV. Let's do this!

[21] http://sticef.univ-lemans.fr/, consulted on the 5th of September 2023
[22] https://www.scopus.com/, consulted on the 5th of September 2023
[23] https://dblp.org/, consulted on the 5th of September 2023
[24] https://www.scimagojr.com/, consulted on the 5th of September 2023
[25] https://www.core.edu.au/conference-portal/, consulted on the 5th of September 2023

TAKE AWAY MESSAGE

This fourth chapter presents an overview of our contributions to the field of TEL and several future research programs.

In the short-term:

- Find more design principles for using game mechanics and HCI to encourage collaborative situated learning

In the medium-term:

- Continue working on authoring tools for Mixed Reality (MIXAP)
- Start new projects on authoring tools for Virtual Reality training environments

In the long-term:

- Try to increase the use of TEL research prototypes in schools by supporting the FORGE: a national open source software repository
- Find new ways to increase the participation of teachers in the design of TEL

In the very long-term, with the entire research community:

- Contribute to a free international open access TEL journal

Annexe A

Appendix: posters of teacher's testimonies

The use of MIXAP created a new learning and cooperation situation, bringing together students from all levels of the school: Kindergarten and first grade, across different learning areas.

MIXAP dynamically and interactively synthesizes various projects previously undertaken with the students at the school.

MIXAP

Adeline JAN
Damien DUMOUSSET

Brûlatte public school, La Gravelle

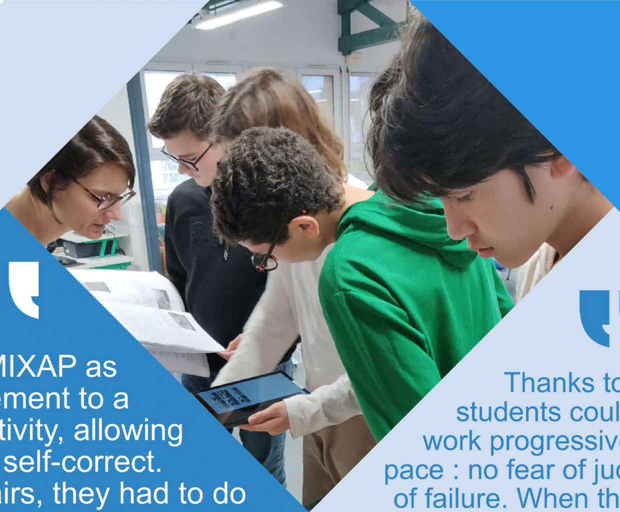
Thanks to augmented reality (sounds, images, texts), the students were able to discover their school courtyard mural in a different way. This new pedagogical approach allows us to diversify and enrich our future teaching methods.

INTERDISCIPLINARITY

LIUM
Laboratoire d'informatique
Le Mans Université

cren
Centre de Recherche en Éducation de Nantes

Le Mans Université

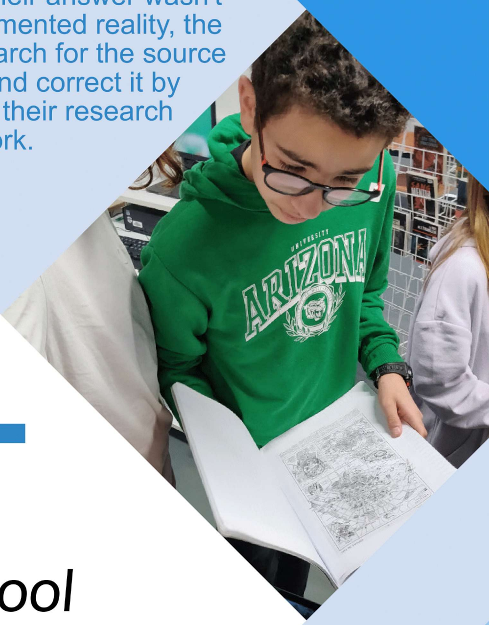


"

I used MIXAP as a complement to a traditional activity, allowing students to self-correct. Beforehand, in pairs, they had to do research involving spatial and temporal identification, as well as information extraction using traditional tools.

"

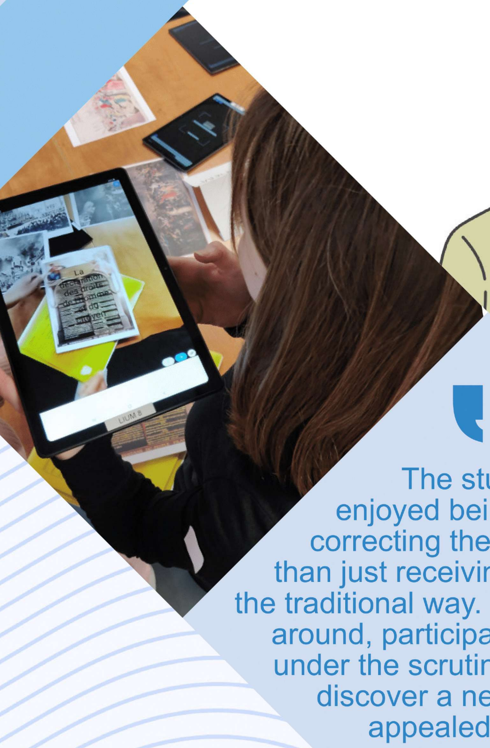
Thanks to MIXAP, students could verify their work progressively at their own pace : no fear of judgment or feelings of failure. When their answer wasn't confirmed by augmented reality, the students could search for the source of their error and correct it by going back to their research work.

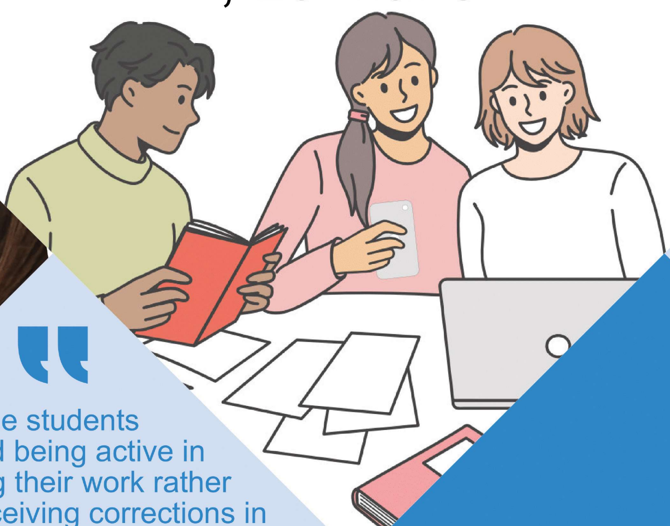


MIXAP

Camille POQUET

Ambroise Paré middle school , Le Mans

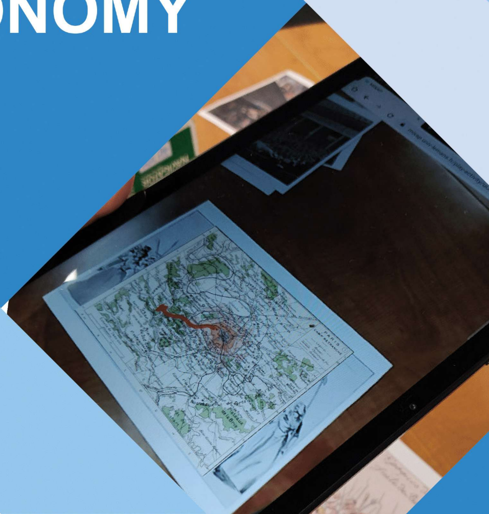




"

The students enjoyed being active in correcting their work rather than just receiving corrections in the traditional way. The ability to move around, participate without being under the scrutiny of others, and discover a new digital use appealed to them.

AUTONOMY



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Région PAYS DE LA LOIRE

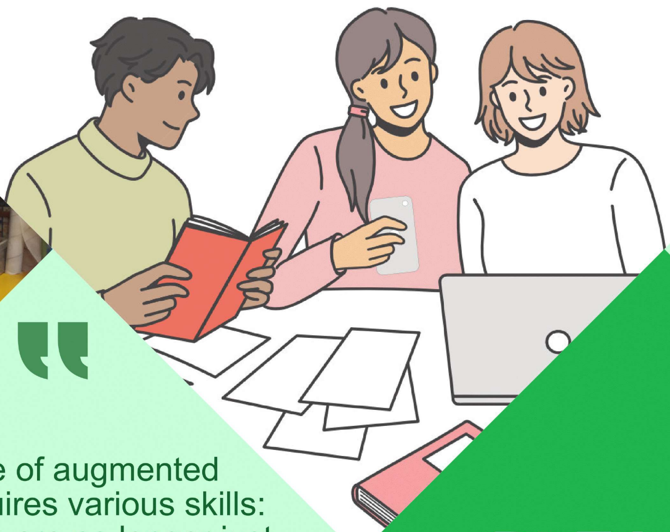
"The goal of my activity is to listen to the songs learned in class this year: to make them their own, remember them, or simply enjoy them."

"All of my students experienced the MIXAP activity, and I continued this work in class. I noticed that they became faster and more skilled over time."

MIXAP

Annabel LE GOFF

Huisserie public school



"The use of augmented reality requires various skills: the children are no longer just "consumers of songs," they truly become active participants in their learning."

PLEASURE

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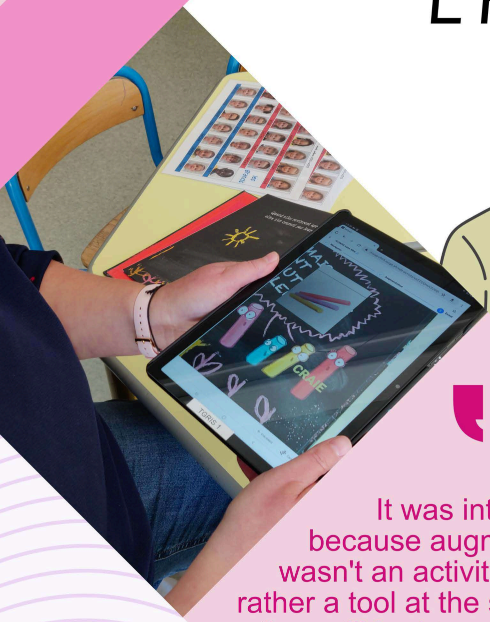
"With MIXAP, I created an activity using a children's book that we had already use in class to reinforce vocabulary acquisition, work on writing these words, and compare illustrations with real objects."

"The students were very enthusiastic about this new activity proposal that required teamwork. They had a lot of fun and all experienced a sense of accomplishment while feeling like they were having fun."

MIXAP

Delphine DESHAYES

L'Huisserie public school



"It was interesting because augmented reality wasn't an activity on its own but rather a tool at the service of learning: they still had to manipulate sheets, images, glue, and pencils... MIXAP became a tool to do the work differently!"

PLAYFUL

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"The objective is to demystify the technical objects that students use or encounter daily, to understand their functioning, and to implement the associated technologies themselves."

"The SEGPA students quickly mastered the MIXAP author interface to enhance a 3D printer with video tutorials and shared the instructions with other students."

MIXAP

Frederic LLANTE

Alain Gerbault middle school

"For me, the interest lies in having a versatile, user-friendly tool that allows students to quickly become independent and can be used on various platforms without an internet connection."

SIMPLICITY

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"

The MIXAP project allowed me to develop activities related to workshop production systems.

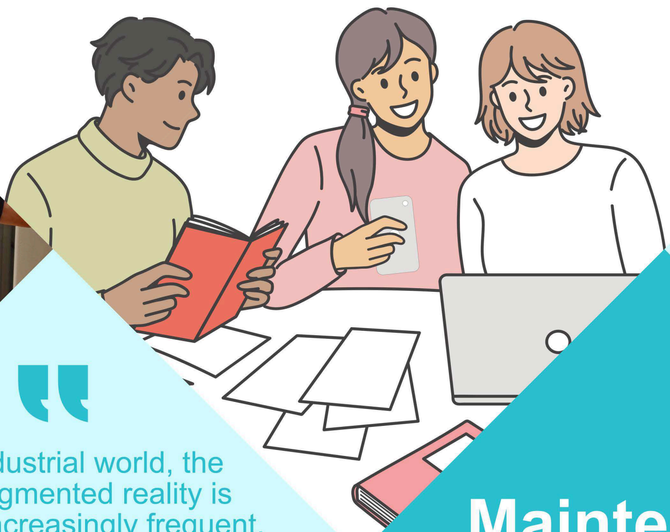
"

With the help of the tablet, the students were able to start industrial systems even without prior knowledge, and they did so independently.

MIXAP

Nicolas GAUDIN

Raoul Vadepied high school - Evron



"

In the industrial world, the use of augmented reality is becoming increasingly frequent. The MIXAP project enables students to use a "technology" that they will likely use in their future professional lives.

Maintenance 4.0

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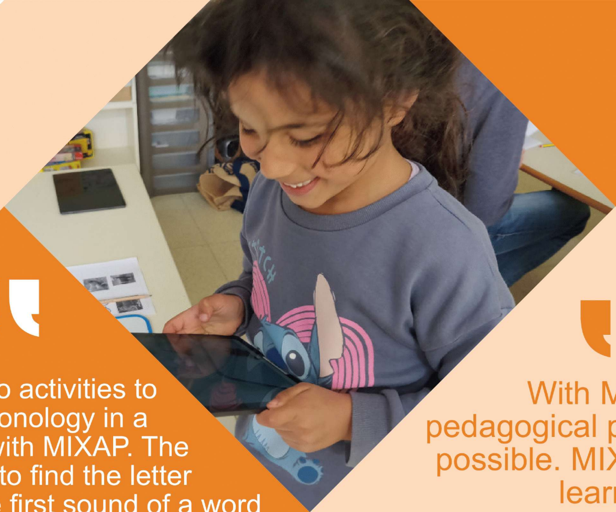

"

I created two activities to work on phonology in a different way with MIXAP. The students have to find the letter corresponding to the first sound of a word represented by a drawing (choose from 3 letters), then a word represented by a photo (choose from the 26 letters of the alphabet).

"

With MIXAP, pedagogical progression is possible. MIXAP promote learning
, autonomy and self-validation. The students also need to fill out a record sheet to keep track of the activity.

MIXAP

Elisabeth PLANTE

Jules VERNE public school, Laval

"

All the students are intrigued by this new way of approaching phonology. The use of a tablet made the activity more engaging. All of them quickly became familiar with the MIXAP application.

MOTIVATION

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"

With MIXAP, I offered them an augmented reality "Seek and find" activity based on a painting discovered at the museum. Once they found the detail (an animal), a real object appeared, and by clicking, they could hear its name.

"

This way, my students were able to reinforce the vocabulary they learned in class and enhance their observational skills.

MIXAP

Vanessa FROC

Huisserie public school

"

In the traditional format, the "seek and find" activity is done independently. With MIXAP, the students were encouraged to cooperate and help each other to succeed.

RESEARCH

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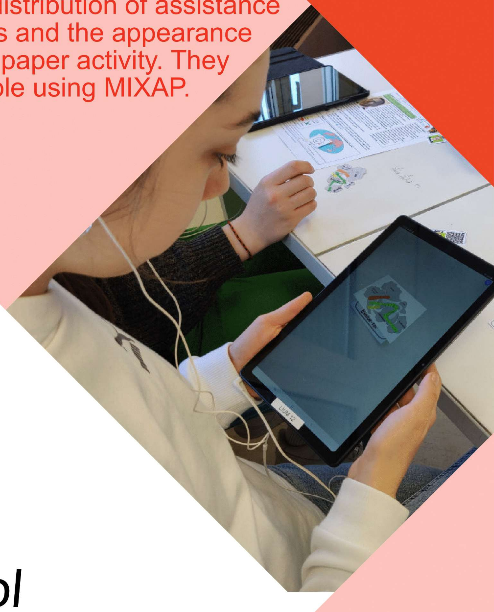
> Thanks to the video , audio and textual help provided by MIXAP , the students were able to use their headphones to answer the initial session problem at their own pace. After proposing an answer, a distributed marker allowed them to self-assess. Everyone completed the task.

> The students were initially independent, immediately engaged in research, then they developed collaboration in using the tool. They appreciated the distribution of assistance based on their needs and the appearance of videos from the paper activity. They were comfortable using MIXAP.



MIXAP

Tony NEVEU

La Foresterie middle school
Bonnetable

> The pedagogy of the session was based on the possibilities offered by the application to allow student autonomy and self-assessment; MIXAP supports my pedagogy.

DIFFERENTIATE

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"

The SituLearn application allowed students to develop digital skills outside the classroom, in a natural environment they are familiar with from regular outings.

"

Through geolocalized activities designed with SituLearn, our students worked on spatial orientation, discovering the world, and cooperation.

SITULEARN

Adeline JAN
Damien DUMOUSSET

Brûlatte public school, La Gravelle

"

This experience opens up prospects for future routes to discover new environments with our students and enrich our teaching practices.

LEARNING

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"

I adapted numerous field trips using the SituLearn application with the intention of enhancing students' learning in natural sciences.

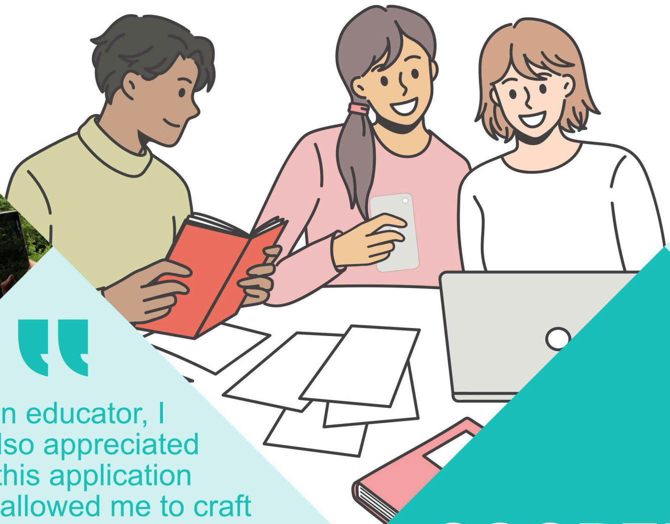
"

The students found the experience interactive and captivating, and they were able to collaborate effectively as a team.

SITULEARN

Guy THEARD

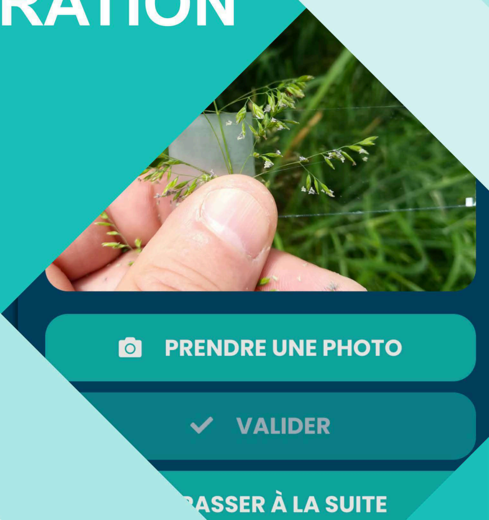
Jules Renard middle school, Laval



"

As an educator, I have also appreciated using this application because it allowed me to craft original teaching scenarios that prompt various activities (MCQs, questions, surveys, etc.) when students reach specific points (geolocated or not).

COOPERATION



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"

SituLearn promotes the engagement of children with disabilities in an epistemic game that allows them to evaluate their skills in navigating an unfamiliar space by finding useful points of interest (POIs)

"

The interest of this epistemic game also lies in generating collaboration among the various players to learn together and engage in prosocial behavior.

SITULEARN

Ludovic BLIN

Medical Education Institute, le Mans

"

This ludic artifact undoubtedly helps to understand the situation at hand—the "played game"—and fosters playful interactions among diverse players towards a common goal : successfully completing the orienteering course.

EVALUATION

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Le Mans Université

"

To make the written, iconographic, audiovisual, and sound heritage of the region accessible to all audiences, the Departmental Archives of Mayenne offer new forms of mediation through new content and tools.

"

The SituLearn app is a great opportunity to (re)discover this place in a fun and educational way, perfect for school and family audiences.

SITULEARN

Morgane ACOU-LE NOAN

Mediator at the Departmental Archives of Mayenne

"

This new semi-autonomous visit format will be offered during the European Heritage Days in September 2023 as part of the building's centenary celebrations.

MEDIATION

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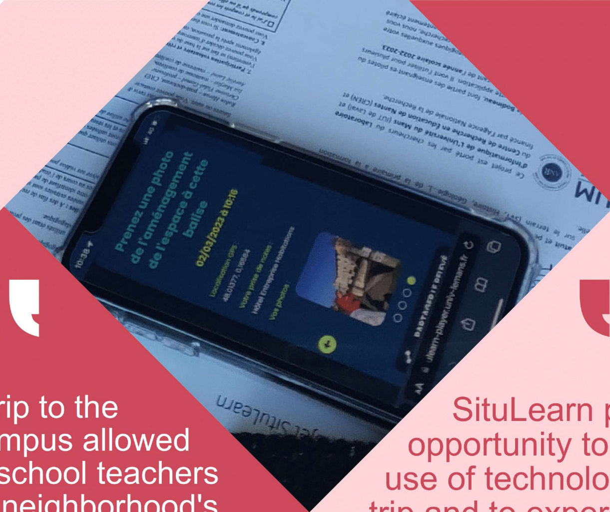

"

A field trip to the university campus allowed future primary school teachers to observe the neighborhood's transformations through an orientation course that combined geography and Physical Education.

"

SituLearn provided an opportunity to showcase the use of technology during a field trip and to experience self-guided routes while directing their observations more precisely.

SITULEARN

Julie BENOIST
Valérie BODINEAU

Physical Education and History-Geography Teachers at INSPE du Mans

"

SituLearn is a training tool that enabled us to implement a pedagogical scenario that future teachers could design for their students

AUTONOMY

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"The first steps of a geologist in the field need close guidance, which is facilitated by SituLearn's geolocalized activities.

"These activities are designed to help our geology students quickly acquire the right reflexes in the field.

SITULEARN

Régis MOURGES

Geology Professor, Le Mans University

"Eventually, the application will allow us to offer activities of different levels for learning and progression in complete autonomy

AUTONOMY

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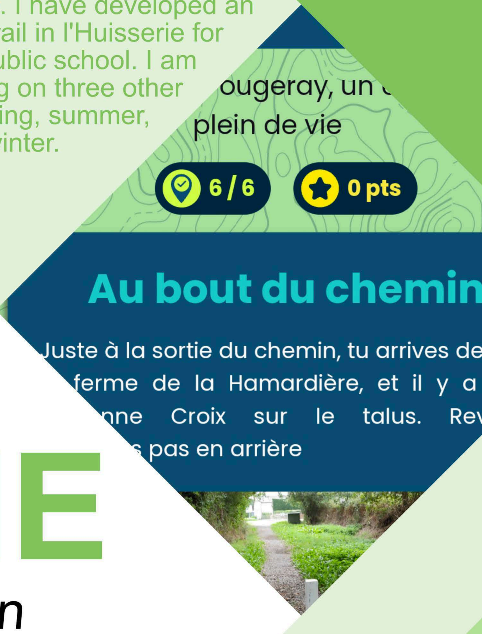
"Mayenne Nature Environnement has established a label called "On the Path of Nature: a Trail, a Pond, a Wood for Each School." Currently, there are 40 designated sites in Mayenne.

"With SituLearn, I am exploring the possibilities of designing educational outings that promote the discovery of nature at these sites, catering to both students and the general public. I have developed an excursion along a trail in l'Huisserie for students of the public school. I am currently working on three other routes for spring, summer, and winter.



SITULEARN

Benoît DUCHENNE

Mayenne Nature Association

"This work challenges and rejuvenates my role as a nature excursion facilitator.

DISCOVERY

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

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Glossary

ADEM Automatic Description Extraction Metadata. 80, 81

AEIF *Assocaition des Enseignants d'Informatique en France*, association of computer science teachers in France AI: Artificial Intelligence. 152

ANR *Agence Nationale de la Recherche*, french national research agency. 112, 146, 149, 156

Canopé French national teacher training center. 105, 139, 144, 148, 153, 154

CSCL Computer Supporter Collaborative Learning. 142, 143

DAN *Délégué Académique au numérique*, person responsible for the digital services for an educational region. 153, 154

DBR Design-Based Research. 56, 63, 66, 75, 76, 77, 78, 79, 87, 105, 129, 138

DIY Do It Yourself. 49, 85, 140

DNE *Direction du numérique pour l'éducation*, educational region authorities. 154

EAFC *Ecoles Académiques de la Formation Continue*, teacher training center. 154

E-FRAN *territoires éducatifs d'innovation numérique*, funding program for educational territories of digital innovation. 149, 154

Edtech Educational Technology. 139, 147, 148, 149, 150, 152, 153, 154, 155

EPUB format Electronic PUBlication format. 157

ERUN *Enseignant Référent aux Usages du Numérique*, teacher in charge of digital technology. 153

FAIR principles Findable, Accessible, Interoperable, and Reusable. 157

FORGE open-source software forge of the French Ministry of Education. 139, 152, 153, 156

GTNum *Groupe Thématique Numérique*, funding program for digital thematic working groups. 149, 156

HCI Human-Computer Interactions. 47, 48, 49, 50, 51, 52, 62, 63, 65, 66, 92, 99, 132, 137, 139

IAN *Interlocuteur Académique pour le Numérique*, academic contact for digital technology. 153

INSPE *Instituts Nationaux Supérieurs du Professorat et de l'Éducation*, national training institutes for teaching and education. 153, 154

LGMD Learning Games Metadata Definition. 80, 81

LOM Learning Object Metadata. 80, 85

Léa *Lieux d'Éducation Associés*, associated educational sites. 146, 149

ML Mobile Learning. 45, 46, 47, 49, 50, 51, 62, 63, 65, 66, 92, 99, 100, 104, 112, 113, 115, 116, 117, 118, 119, 120, 125, 128, 132, 137, 139, 146

MR Mixed Reality. 70, 102, 103, 104, 105, 108, 109, 110, 111, 128, 132

ODT format Open Document Text format. 157

OER Open Educational Resources. 92, 156

PDF Portable Document Format. 144, 157, 159

PIA *Programme d'Investissements d'Avenir*, investment program for the futur. 149

PoC Proof of Concept prototype. 152

POI Point Of Interest. 113, 114, 115, 118

SATT societies *Société d'Accélération de Tranfert*, transfer acceleration company. 155

SG Serious Games. 6, 44, 45, 51, 52, 62, 63, 64, 65, 70, 71, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92

SUP School-University Partnership. 55

SUS System Usability Scale. 83

TEL Technology Enhanced Learning. xi, 39, 40, 41, 42, 43, 45, 49, 50, 51, 53, 54, 55, 56, 57, 61, 62, 63, 65, 66, 72, 76, 77, 78, 79, 80, 85, 92, 93, 99, 100, 101, 102, 105, 111, 126, 127, 128, 129, 130, 131, 132, 138, 139, 142, 147, 148, 149, 150, 151, 153, 154, 155, 156, 157

UDID User-Driven Interface Design. 81, 82, 83

UML Unified Modelling Language. 57, 129

UX User eXperience design. 63, 102, 131, 139, 148, 153

WISIWIG What You See Is What You Get. 116

ZPD Zone of Proximal Development. 41

COLLEGE DOCTORAL PAYS DE LA LOIRE — ED MATHEMATIQUES STIC

Le Mans Université

Title: Designing Serious Games, Mobile Learning and Extended Reality Applications for and with teachers

Keywords: Technology-Enhanced Learning, Serious Games, Serious Games, Mobile Learning, Human-Computer Interactions

Abstract: This manuscript presents our main contributions in Technology-Enhanced Learning (TEL) and in particular how Serious Games, Mobile Learning and innovative Human-Computer Interactions, can be designed and used to improve learning at all levels, from pre-school to vocational training.

We have addressed two main challenges. First, we provide methods, models and tools to help all the necessary actors, including teachers, game designers and developers, to design effective TEL systems. Through multiple projects, tested in classrooms, we identified several design principles that contribute to the research community. Our second challenge is to facilitate the creation of TEL systems by teachers themselves and thus increase their acceptability and use in schools.

In particular, we developed adaptable models and authoring tools to help teachers create two types of TEL systems: Mixed Reality educational activities and geolocated smartphone applications for field trips.

On the basis of these contributions, a research plan is presented for the future. In the short-term, I plan on exploring ways to encourage collaborative situated learning. In the middle-term, I plan to continue working on authoring tools with European partners. And, in the long-term, I would like to pursue a more ambitius challenge which is to increase the impact of TEL research in French schools. This implies proposing open-source software architectures to encourage collaboration among researchers, education technology companies and teachers.

Titre : Conception de Serious Games, d'Applications mobiles et de Réalité Étendue pour et avec les enseignants

Mots clé : Environnements Informatiques pour l'Apprentissage Humain, jeux sérieux, application mobile, Interactions Humain-Machine

Résumé : Ce manuscrit présente nos principales contributions dans le domaine des Environnements Informatiques pour l'Apprentissage Humain (EIAH), et en particulier comment les jeux sérieux, les applications mobiles et les Interactions Humain-Machine innovantes peuvent être conçus et utilisés pour améliorer l'apprentissage et la formation professionnelle.

Nous avons relevé deux défis principaux. Premièrement, nous fournissons des méthodes, des modèles et des outils pour aider tous les acteurs impliqués, tels que les enseignants, les *game designers* et les développeurs, à concevoir ces EIAH. Grâce à de multiples projets testés en classe, nous avons identifié plusieurs principes de conception qui contribuent à la communauté scientifique. Notre deuxième défi est de faciliter la création d'EIAH par les enseignants eux-mêmes et ainsi augmenter l'acceptabilité et l'utilisation de ses outils dans les écoles.

En particulier, nous avons développé des modèles et des outils auteurs pour que les enseignants puissent créer deux types d'EIAH : des activités éducatives intégrant de la Réalité Mixte et des applications mobiles géolocalisées pour les sorties scolaires.

Sur la base de ces contributions, un plan de recherche est présenté pour l'avenir. À court terme, je prévois d'explorer comment la technologie peut encourager l'apprentissage situé collaboratif. À moyen terme, je prévois de poursuivre mon travail sur les outils auteurs avec des chercheurs européens. Et, à long terme, j'aimerais relever un défi plus ambitieux pour accroître l'impact de la recherche en EIAH dans les établissements d'enseignement français. Cela implique la proposition d'architectures logicielles libres pour encourager la collaboration entre les chercheurs, les entreprises de technologies éducatives et les enseignants.