Toward a Digital Companion to Monitor a Mixed Reality Game

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Abstract

The game orchestration by the game master during a game-based learning session requires to (1) collect data from player interactions, (2) visualize indicators built with this data, (3) take decisions regarding the monitoring of the activity and (4) interact with players. The complexity of this monitoring increases with mixed-reality games due to the multiplicity of possible interactions with tangible and digital game elements. This article deals with playing analytics and the design of a digital companion to help a game master to orchestrate Geome, a mixed-reality game dedicated to museum school visits. The prototype is the result of a co-design process between researchers, practitioners, and computer scientists. This work allowed us to (1) define the interactions established during the use of the game that should be traced for the game master and (2) test the prototype with 3 classes (12-15 years old). We found that, while the players play the game as intended using most of the features, the game master makes little use of his dashboard and doesn't interact with players through the dedicated interface.

Keywords: *Game Orchestration, Game Master, Mixed-Reality Game, playing analytics;*

1 Introduction

In an educational context, game integration shifts the students and teacher's roles. Indeed, the roles of the students and the teacher evolve, respectively as players and game master. From the game master perspective, the teacher is responsible for setting the fictional contract [1], delivering narrative control through interacting with players, ensuring that all players know and understand the game rules and ensuring players engagement by providing constant challenges [2]. Many studies have been carried out to assist the teacher, while monitoring learning activities, with dashboards [3] and orchestration tools [4] i.e the means given to the teacher to organize and manage, in real time, activities and the various interactions that result from it. However few papers address this issue for game-based learning and research on the role of the teacher in game-based learning is still in its infancy [5] especially for role-playing learning games, escape games and mixed-reality games that combine digital game elements, physical and social aspects of traditional game play [6]. The control of the game world by the game master during the activity requires a precise monitoring of the activity which increases in a mixed-reality game context due to the multiplicity of possible interactions with the tangible and digital game elements. How can these interactions be described and categorized? To what extent can they be traced and provide useful information for the game master?

This paper deals with 2 main goals: players' activity recording and information needed by the game master for the activity monitoring in a mixed-reality game context. The main contribution of this paper is a model that describes the different categories of interactions that take place in a mixed reality game. Based on this model, a prototype was developed and tested in a naturalistic context. Thus, we also provide empirical elements that allow us to evaluate the relevance of choices made for the development of an application dedicated to the game monitoring. Indeed, we address these issues with the development of *DigitComp*, a digital companion dedicated to the collection and reporting of data from players, and the game monitoring. The design, the development and the implementation of the prototype result from a collaborative work between researchers, practitioners and computer scientists.

In the next section, we present the game and the context for its use. In the third section we introduce the theoretical framework and the model on which our study is based. Indeed, game based-learning is considered to encompass 3 levels of interactions: interaction between players and the game, interactions between players and interactions between players and the game master. The design-based method of our study is presented in section 4. In the last section, we present and discuss the results of the *DigitComp* design process and the empirical work carried out in a museum.

2 Game-Based Learning during Museum School Visits with Geome

This paper presents our research results which deals with the orchestration of a mixed-reality game (*Geome*) dedicated to school visits in a nature museum. Our goal is to identify information and tools needed by the game master for the game orchestration. *Geome* (Fig. 1b) is a two-parts mixed-reality game played in the Nature Museum located in Switzerland. Mixed Reality (MR) is a particular subset of Virtual Reality. MR involves the merging of real and virtual worlds [7]. Thus, the expression mixed-reality game denotes games that use mixed reality setups [8]. The player is involved in a game where information is provided both by its tangible environment and from digital devices (digital information). By ways of examples, *Ingress* and *Pokemon Go* are two mixed reality games which have been very successful and had a large audience. *Geome* is played in teams with digital tablets. From the player perspective, information needed to play comes from the museum exhibition and from the digital tablet and the player interacts with both tangible and digital elements.

Geome is dedicated to museum school visits tailored for secondary school students (12 - 15 years old). The game encourages the students to question their relationship with nature. Thus, the expected learning outcomes are linked with the Anthropocene understanding, a geological period in which human beings no longer consider themselves as part of nature but over-exploits it with many consequences on biodiversity and climate change. Another expected learning outcome of the game concerns the students' relationship to knowledge. During the game, they are expected to question the nature of knowledge (certainty and complexity), and the way it is produced (source and justification) [9]. Indeed, the issues related to the Anthropocene are ill-structured problems [10]. There is no unique solution and they cannot be solved with a high degree of certainty. Dealing with such complex problems is partly related to individual scientific literacy and personal epistemology (i.e. relationship to knowledge). It is generally accepted that, if students understand the source and limitations of scientific knowledge, they will be better prepared to make informed decisions about personal and societal problems that are scientifically validated.

The design of the game scenario takes into account the museography in order to promote interactions between players and the museum tangible elements, but also to settle a coherent game narrative. Indeed, the permanent exhibition of the Nature Museum includes collections of fauna, flora, and geology of the local environment, distributed in several rooms and 2 floors (Fig. 1a). The museum narrative focuses on the historical evolution of the relationship between human beings and their environment.

Figure 1. *Geome, a game played with digital tablets in the Nature Museum*

The game session lasts about 1h30 including 2 distinct parts and debriefings that follow each part of the game. The players play as teams of 3 or 4 players. They play the role of a wildlife expert who lives in an alpine valley. In the first part of the game, the character they play is stuck in the valley because of the winter weather conditions. He needs to gather resources to survive. For the players, this means scanning the stuffed animals displayed in the different museum rooms. A QR code provides access to information related to each scanned animal such as its name and a scientific description. Depending on the decisions of the player, each animal is then captured, killed, or domesticated. Therefore, the players collect resources such as meat, leather, milk, eggs… necessary for its survival. The players may also choose to walk away and to do nothing with the animal. All the resources, collected or produced, as well as the animals captured, enrich the player's inventory. At any time, the player may decide to exchange his resources with another team to reach the number of resources needed to win the game individually. However, all team actions impact the same “tree of life”, a metaphor of environmental quality (Fig. 2c). Thus, in collecting resources, the players collectively lose by depleting the "tree of life" energy. This first part of the game lasts 10 to 15 minutes and the students cannot win.

In the second part of the game, freed from the constraints of winter, the character can return to his work. He is called, as a wildlife expert, to solve fake news, rumors or polemics related to the natural environment. After being introduced about the problem to be solved by reading a character’s interview, the players search for tangible clues provided by the museography (print, photo, skin). By scanning the QR code of the clues, the players investigate the museum exhibition and access the needed information (Fig. 2b) for solving the puzzle and drawing an ecosystemic map that describes the relationships between the living beings of the ecosystem. The ecosystemic map makes visible the complexity of the natural ecosystem interactions. During the game, the players assess the information provided by the game characters by answering 2 quizzes.

The victory depends on the players’ capacity to identify the complexity of the relationships between animals and to develop critical thinking regarding the information provided. Indeed, interactions within an ecosystem are not limited to predation as stated in the first part of the game. Through inquiry and the collection of the available information when they scan an element from the exhibition, they discover relationships of a different nature such as habitat, competition, and mutual aid. The more relationships they report on the ecosystemic map, the more points they earn. At the end of the game, they get a success rate on their scoreboard compared to the "expert" systemic map.

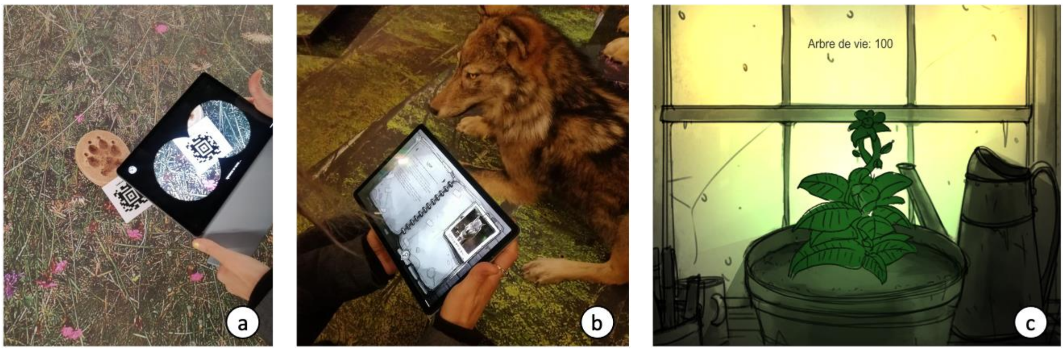

Figure 2. *Geome, a two-parts mixed-reality game*

Thus, the player adopts successively 2 postures during the 2 parts of the game: that of the predator who exploits his natural environment, then that of the investigator who brings to light the complex interspecific relations within the ecosystem. The scenario includes a debriefing phase after each part of the game. This moment is conducted by the museum mediator. The debriefing is based on a model described by Plumettaz-Sieber, Sanchez & Bonnat [11]. It takes the form of a discussion with the players. First, the discussion focuses on the players' experience during the game and their feelings during the game. It also aims at explaining the meaning and to make visible the learning outcomes of the game. The museum mediator also helps the students to find analogical real-life situations to insure the transfer of knowledge. During debriefings, the students are led to question their relationship with nature, but also to analyze their relationship with the media and information. The debriefing also aims to deconstruct the game metaphor which is a "simple" and concrete learning situation of a more complex and abstract domain [12].

Due to the complexity of interactions during the game and the constraints generated by the museum (rooms distributed on 2 levels), the role of game master (taken by the museum staff) is crucial. Indeed, the game master is responsible for setting the fictional contract [1] so that the player enters the so called "magic circle". The game master is also intended to interact with the players, ensuring that they know and understand the game rules and fostering players engagement by providing constant challenges [2]. The monitoring of learning activities with dashboards and orchestration tools is a very active research area. However, we lack research on the game master role and tools for game-based learning [5].

As a result, our work consists of: (1) Identifying the different interactions that take place to provide the game master with relevant information about: what the players do? what they perceive? what they feel? and what they learn? (2) Providing the game master with the tools needed for the game orchestration.

Beyond the specific use case concerned by our empirical research, we consider that our contribution to the field is both theoretical (i.e a better understanding of the interactions that should be tracked for providing the game master with the information needed for the game orchestration) and practical (the test of specific features dedicated to track players interactions during a game-based learning session). In the next section we describe the different levels of interaction that need to be considered.

3 Four Levels of Interactions for Game-Based Learning

Game-based learning results from the implementation of different categories of interactions. The first category consists of interactions between the player and the game or his opponents. These interactions are competitive in nature and result in what Salen and Zimmerman refer to as an "artificial conflict" [13]. The player attempts to meet challenges by implementing strategies that evolve based on successes and failures. The player may therefore have to change the way he thinks and acts depending on the feedback from the game or opponents. For example, by playing *Geome*, a player may notice that collecting resources in the museum decreases the energy level of the tree of life (Fig. 2c). He is expected to make a causal link between exploitation of natural resources and ecosystem degradation. This is an *action situation* according to Brousseau [14].

A second level of interaction concerns the interactions between the players themselves. This level consists of collaboration between teammates. Each player is led to communicate, to teammates, the winning solutions and strategies that will allow them to overcome the challenge. These verbal interactions lead the players to formulate and establish the validity of the knowledge needed to win. Brousseau describes these situations as *formulation* and *validation situations*. This is what happens when players who solve the puzzles in *Geome* discuss and decide to stop collecting resources to avoid the decrease of the tree of life's energy or when they trade resources.

The third level of interaction concerns the exchanges between the game master (museum staff) and players. We call orchestration this level of interaction. Depending on the information collected, the game master makes decisions that allow the game to run smoothly. There has been little research on this issue [5]. However, we know that the game master intervenes in different ways and takes different kinds of decisions. First, the game master must encourage the player to enter the magic circle [15], i.e. help him/her to interpret the situation as a game. This requires the construction of a narrative and to encourage storytelling for keeping the narrative flowing. Thus, he is responsible for providing dynamic feedback to the actions of the players "on-the-fly updates" [2]. This also requires establishing a ludic contract that sets the rules of the game and thus, allows the game world to be set up and maintained [16]. Among the decisions taken by the game master, one is to stop the game. For example, in the case of *Geome*, the game master may send a message to the different teams to tell them that they have lost, to ask them to meet in the room where the debriefing will take place.

The debriefing is another level of interactions. During the debriefing the game master becomes a museum mediator again and students are not players anymore. Thus, interactions take place between the museum educator and the students. The debriefing is based on students' gaming experience. As a result, traces of this experience are needed both by the students who may reflect about their experience and by the museum mediator who may ask questions and find arguments based on what the students experienced.

These situations, competition (action), collaboration (formulation and validation), orchestration and debriefing are thus distinguished by the nature of the interactions that take place and by who is involved in these interactions: player-game, player-player, game master-player or teacher-students. They can be represented in the form of 3 nested interaction levels (Fig. 3). This representation is inspired by Margolinas'work [17]. It allows us to distinguish the different categories of interactions that may be traced and to select the interactions that may be useful for the orchestration of the game and the debriefing. We use this model to design *DigitComp*, a digital companion dedicated to assist the museum educator for the game orchestration and the debriefing.

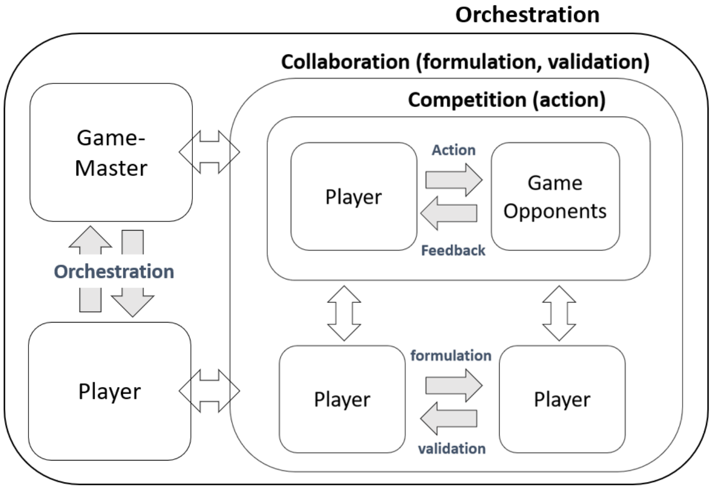

Figure 3. *Different situations and interactions for game-based learning.*

The use of this theoretical framework allows the categorization and description of the interactions in a game-based learning situation, which is the first step of our work. Indeed, based on this model, we wonder about the traceability of these interactions in order to provide useful information to the game master. More precisely, in the context of the orchestration of a mixed reality game played in a museum, we focus our research on the following questions:

- What types of interactions can be tracked and from what kind of data?
- What types of interactions are needed for the orchestration of the game?
- What features should be implemented for the tracking of these interactions?
- What are the results regarding the use of these features by the game master?

4 Research Methods

4.1 A Design-Based Research methodology

The research work consists of a Design-Based Research methodology [18] [19] [20]. This multidisciplinary approach (learning sciences and computer sciences) relies on the collaboration of researchers with practitioners, i.e. teachers and museum staff, for the co-design and the co-evaluation of the digital companion. Indeed, practitioners and researchers are both involved in the design (co-design) and the testing of the prototype, and the interpretation of the data collected (co-evaluation). The process is also iterative. It includes different cycles for the design and evaluation of the prototype, with the possibility, for each iteration, to modify the prototype and the theoretical models on which it is based. For this purpose, the prototype is tested in a naturalistic context, i.e. at the Nature Museum, with 63 secondary school students (12 to 15 years old) and the museum mediator involved in the research as the game master. In this paper we present the results from the 2nd iteration of the co-design process, i.e. the second version of the digital companion. For this we take as a starting point the co-design process of the first prototype and its evaluation with users, according to our research questions and framework.

The first iteration for the design of the game and the digital companion was carried out in parallel during 16 workshops organized in 3 steps. The method is inspired by the ADDIE learning design framework [21]. This framework encompasses 4 steps: Analysis, Design, Development and Implementation with continuous Evaluation (fig. 4).

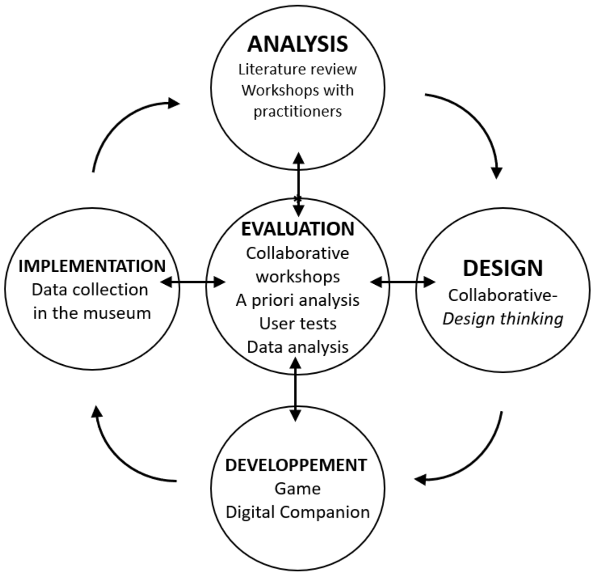

Figure 4. *Design-based research design inspired by the ADDIE framework*

The first step consists in positioning our research problem according to existing works. As a result, the design is based on the model described in the previous section. Thus, the design of the game and the digital companion considers 3 different levels of interactions. The collaborative work with the museum mediator enabled us to take in consideration her expectations and the constraints she faces for the game orchestration: configuration of the museum's rooms, technical considerations for the game launching, information needed from the players, nature of the interactions with the players, etc.

The second step focuses on the digital companion design, which supports the game master's interactions within the game: i.e the tracking of the players' interactions. The functions have been designed to meet the game master's needs before, during and after the game respectively to set up the game, to monitor the activity of the players, to interact with them, and to carry out the debriefing based on the information provided by the collected traces.

For this purpose, we used a didactic modeling of the game according to Brousseau's theory of didactic situations [14] in order to set the game variables that define the parameters of the game (time, energy level available to the players, difficulty of the puzzles...). Concerning the monitoring of the players, we have taken into account the levels of interaction. According to our model (fig. 3), there are 3 levels of interaction during the game session: player to player, player with the game interface and the museum exhibition, and the interactions with players in terms of game orchestration (decisions taken by the game master). This step allows for the identification of the traces to be collected according to a didactic analysis of the game *Geome* [22] which highlights the main learning objective. In addition, it highlights the way to display these traces for the synchronous monitoring of the players' activity by the game master. The choices made for the design of the game master interface are assessed during workshops.

The third step consists of the development of *DigitComp* and also the connection of all the game elements, in order to collect and visualize the digital traces. We carried out an *a priori* analysis of the possible interactions required in the game in order to identify hypotheses on which our experiment protocol for the co-evaluation process is based. Tests carried out with the team members were dedicated to reviewing the game. They also offer the opportunity to review the digital companion to ensure data recording and to debug the game master's interface.

The fourth step that is described in the following section, consists in implementation for data collection during naturalistic game sessions.

4.2 Data collected and data analysis

The first iteration of the research consists of 3 different game sessions that took place in February 2021 at the Nature Museum. The 63 students were divided into teams of 3 or 4 players. Teachers participated for the classroom management and the role of game master was taken by the museum mediator. She set up the game universe with a 5-minutes briefing which was expected to foster students' engagement. She was, according to the decisions taken during the co-design workshops, responsible for monitoring the game. It means interacting with players, answering question, providing guidance and support based on the information about players' activity. This information is available thanks to the game master application (*DigitComp*).

As game master, the museum mediator is also responsible for the debriefings that follow the two parts of the game. These debriefings consist of a discussion with players about environmental and media literacy issues. This discussion is based on a guiding questionnaire. The design of this guide follows the recommendations for debriefing [23]. The debriefings last approximatively 20 minutes. The museum mediator participated in the whole co-design of the pedagogical scenario, including briefing, the game and debriefings. She also participated in a test to get familiar with the game master interface. During the 3 game sessions, researchers acted as observers and the computer scientist provided technical assistance. Notes were collected by the researchers on the game master's use of *DigitComp* and discussed during the co-evaluation workshop. Indeed, the game master's interface wasn't yet tracked during the 3 game sessions (they are currently being tracked).

The game sessions enabled for the data collection from students' interactions and to test the digital companion functionalities. The digital traces of the players' interactions with the tablet, and their interactions with the tangible elements of the museum exhibition (scan of animals or clues) are recorded in a database in JSON format.

A workshop with all the project members was dedicated to co-analyze data and to discuss what type of interactions have been set up and tracked during the game, but also their nature, according to the ones described by Fig. 3 (interactions with the game, with other players, with the game master). In order to create visualizations of the actions performed by the players, data has been converted into a csv format, cleaned and pre-processed (Fig. 5). The final dataset encompasses the teams' identification (id), a timestamp (tps mn), the action performed by the player (Verb) click, watch, scan, drag and drop, the element of the interface concerned by the action (Subject) and the indicator name indicator of the performed action (Name).

Author I	TimeStamp	Verb	Subject	Name
9	20210208T15:16	click	button	Btn-Clue-RightClue
9	20210208T15:16	watch	clue	Empreintes
9	20210208T15:16	click	button	Btn-Clue-RightClue
9	20210208T15:16	watch	clue	Plumes
10	20210208T15:16	click	button	Btn-Menu-Tree
9	20210208T15:16	click	button	Btn-Clue-RightClue
9	20210208T15:16	watch	clue	Empreintes
6	20210208T15:16	dragndrop	element	0
10	20210208T15:16	click	button	Btn-Tree-Back
10	20210208T15:16	click	button	Btn-Menu-Document
8	20210208T15:16	click	button	Btn-Back-QR
6	20210208T15:16	click	button	Btn-Eco-Back
8	20210208T15:16	click	button	btn-document-objectifclue-0
10	20210208T15:16	click	button	btn-document-objectifclue-2
9	20210208T15:16	click	button	Btn-Clue-Back
9	20210208T15:16	click	button	Btn-Menu-Document
8	20210208T15:16	scan	clue	clue-0
10	20210208T15:16	scan	clue	clue-2
8	20210208T15:16	watch	clue	Plumes

Figure 5. *CSV file of the processed data*

Besides, the use of *DigitComp* by the museum staff was discussed in regards to the different functionalities developed. The observations made during the game sessions and the discussions during the co-evaluation workshop were reported. This first co-evaluation process has contributed to reviewing the prototypes and the research protocol. Thus, based on the articulation of these 2 research processes, we present the second version of the digital companion by specifying the evolutions made following the feedback from the data collected during the game sessions.

4.3 Ethics and data privacy statement

The study was conducted according to the criteria provided by “privacy by design” [24]. In particular, the collection was limited to the data useful for the study. We used data storage with protected access for the researchers of the project and a deadline for destruction. All participants gave written informed consent to participate in the study and the measures taken were formalized by a data management plan.

5 A Digital Companion for the Game Master

We present the results for the co-design process of the *DigitComp* by describing the functionalities offered to the game master to monitor the activity. Then we present the implementation results, i.e. data collected during the 3 game sessions, and its analysis. We describe the collected traces which highlight the way players used the game, and we analyze them according to the three levels of interactions presented in the model described in section 3.

5.1 DigitComp and game orchestration

DigitComp offers 4 interfaces (Fig. 6a) dedicated to the game orchestration: a configuration interface, 2 communication interfaces (chat and automatic feedback), and an activity monitoring interface.

Before the game starts, the game master may set the game parameters (Fig. 6a) with the digital companion interface. For example, he/she may define/modify the game objectives (number of resources to collect), choose the duration of the game, assign specific quests to the different teams according to the students’ level. Besides, the digital companion offers the game master the possibility to schedule automatic feedback to players. For example, an automatic message may be sent if the energy level of the "tree of life" (Fig. 2b), which represents the points earned or lost by the players, reaches a threshold that the game master considers as critical. Currently, these parameters cannot be changed after the game starts.

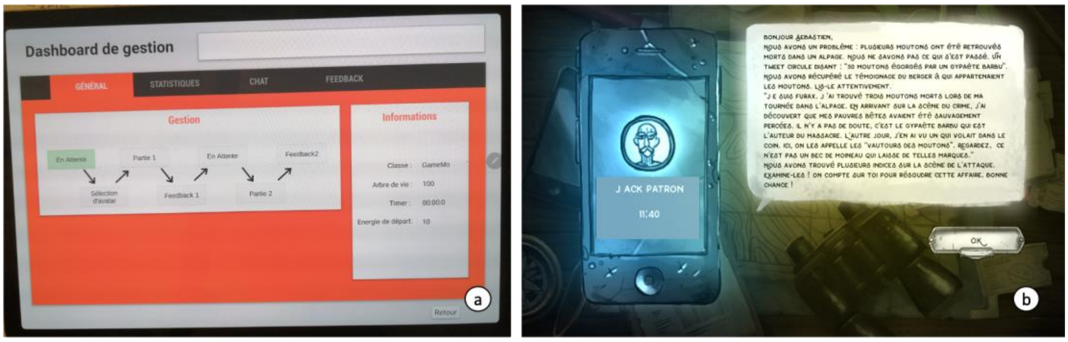

Figure 6. *DigitComp, an interface between the game master and players*

DigitComp also includes a chat room enabling synchronous communication between the game master and players (Fig. 6b). The chat room is integrated as an element of the game narrative, i.e. the head of the wildlife experts is intended to send instructions and provide guidance. As a result, the game master takes a specific and active role in the game narrative. At any time, he/she may provide help and guidance to a team of players. For example, the guidance may take the form of a clue needed for solving the puzzle. Teams of players receive notifications via a smartwatch (Fig. 7c) when a new message is available on the digital tablet. Players are free to use the chat room if they need to answer or ask questions to the game master at any time. The chat room allows the game master to overcome the difficulty to communicate with the players displayed in the different museum's rooms. In addition, it offers the opportunity to provide the players with tailored assistance.

Through these different features that can be used and modified by the game master, the game orchestration is “manual” in order to take into account constraints and classes specificities (e.g. visiting time, students’ age). However, “a default” configuration is implemented according to a game scenario model, so that the game master can also use it. Indeed, all the game parameters (e.g. time for each part of the game, % of available energy...) and automatic feedback (e.g. end of game) were defined *a priori* during the game design process. This choice meets the museum mediator’s need i.e. a simple and quick use of the *DigitComp*.

Thus, *DigitComp* is a toolbox dedicated to support the interactions between the game master and the players (orchestration situation). This support requires real-time tracking of the players’ activity described in the next section.

5.2 DigitComp: tracking players’ interactions

Geome and *DigitComp* are two distinct applications connected to the same MQTT (Message Queuing Telemetry Transport) server. More precisely, *DigitComp* is composed of two interfaces, the one which allows to set up the activity, and a dahboard which allows to visualize indicators of players’ activity based on the recording of digital traces (web application). All of them communicate via the server linked to the same database. The data are recorded in JSON format and Experience API (xAPI) Standard. The traces are automatically collected from the player (physiological parameters collected by the smartwatch such as the heart rate) (Fig. 7c), from the interactions of the players with the tablet (Fig. 7a), and from the interactions with the tangible elements of the museum exhibition (scan of stuffed animals) (Fig. 7b) via QR codes that identify stuffed animals. The communication between the tablets (players, game master) and the connected watches relies on the WIFI network of the museum.

Figure 7. *Multimodal traces from different interactions during the game*

These traces are made available to the researchers (raw data). In addition, aggregated data allows for the building of indicators displayed with an interface dedicated to the orchestration of the game [3].

Different indicators are built and made available to the game master (Fig. 8a). These indicators reflect the evolution of the game, such as the evolution of the energy of the "tree of life" according to the gain or loss of points. They also reflect actions performed by players with the tablet, which may or may not interact with the tangible elements of the museum. For example, during the game, players are asked to investigate elements of the museum (stuffed animals). Each element of the museum is identified with a specific QR code and the use of the "scan" function in the game (Fig. 7b) allows the game master to know the elements the player interacts with. Finally, regarding the issue of assessing the player's engagement into the game, emotions [25], a smartwatch worn by one of the players of each team, collects physiological data (heart rate).

With the dashboard, the game master may review, for each part of the game, the interactions of a single player, a team or all the teams (Fig. 8a).

Aggregated data show, for each team, the percentage of objectives achieved, and the impact of all the actions performed by the players (number of animals hunted / protected / domesticated) on the tree of life. Then, for all teams, the game master accesses to detailed statistics such as the impact of the different actions "hunt, protect, domesticate, flee" in part 1. These statistics are linked to learning objectives. Indeed, the impact of individual and collective actions on the availability of natural resources is a main learning goal. This information is useful to the game master and is available in the activity monitoring interface. It is also available in the players' dashboard during the debriefing phase. The game master may also access the information of each team, which are detailed. As an example, for the first part of the game, he/she may access information about resources collected by each team of players according to the objectives defined in the game (ex. quantity of meat, number of skins…).

For the second part of the game, the game master follows the progress of the students' investigation by accessing information about the elements of the museum with which the players interact (different scans of the QR code). The game master gets information about the clues collected by the different teams and what they managed to achieve. For example, He/she get information about how many links the players drew between the element of the ecosystem map (fauna, flora and the environment). The capacity to depict the complexity of the ecosystem is one of the main learning objectives.

The game also encompasses a player's dashboard (Fig. 8b). It provides an overview of the actions performed (number of animals hunted / protected / domesticated), the resources collected (ex. quantity of meat, number of skins…), the points earned or lost. In addition, the smartwatch displays the state of the "tree of life" (Fig. 7c) and generates a notification (vibration and text message) to inform that a a message was set by the game master. The debriefings start with a discussion about players' achievements based on information displayed by the dashboards.

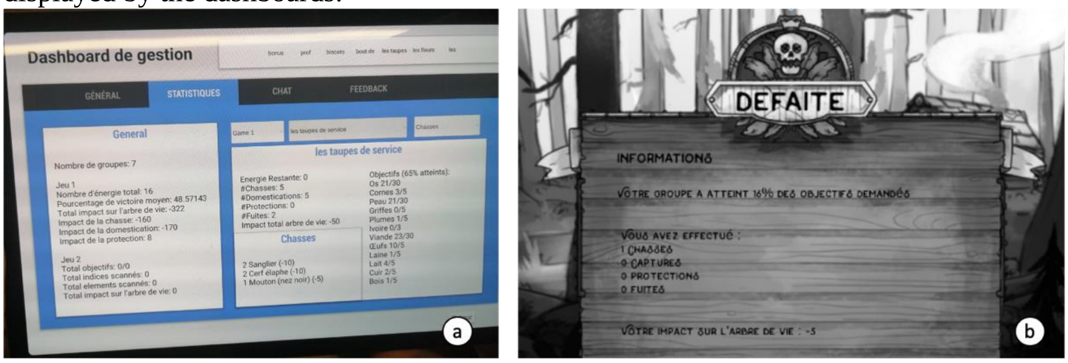

Figure 8. *Dashboard for the game master (a) and players (b)*

Fig. 9 summarizes the interactions tracked or enabled by *DigitComp*. *DigitComp* tracks the interactions from the action situation (in blue, i.e. scan of an animal, loss of points). It also tracks the interaction between players through the interface (in green i.e. trading of resources between 2 teams). *DigitComp* makes available this information for the player (in light grey) and the game master (in dark grey) through the player and game master dashboards. However, oral interactions between players (formulation and validation situation) were not tracked during these 3 game sessions (this function has since been added). At last, *DigitComp* enables interactions for the game orchestration (in red, i.e. sending or receiving a message).

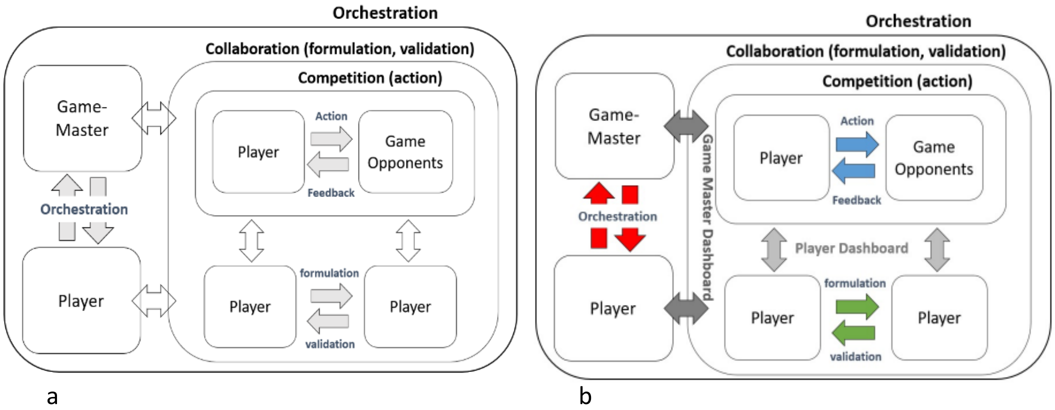

Figure 9. *a Situations and interactions for game-based learning (Fig. 3). b Interactions tracked and enabled by DigitComp*

5.3 *Results from the play sessions and lessons learned*

This section is an overview of the types of interactions [17] implemented and tracked during the 3 game sessions to discuss the limits of the approach and perspectives for the reengineering of the artifacts (*Geome* and *DigitComp*) for the next iteration. Table 1 summarizes the types and numbers of interactions collected during the whole game session for each class named A, B and C (click, watch, scan or drag-and-drop). Digital traces are aggregated according to the main tasks performed by the players. For example, for the second part of the game, actions which refers to the investigation task, and the ones which refers to the ecosystem maps, are distinguished because these categories refer to the two main learning tasks. However, for the first part of the game, among the different interactions, and in relation to the three levels described in the theoretical model, we distinguish interactions defined as "individual" actions, such as hunting an animal by scanning it, from the "collective" actions that include several teams, such as those relating to exchanges of resources.
Due to technical issues during the recording of the traces during the first game session, data from the second part of the game are not available. We discuss the results according to the different levels of interaction for game-based learning (Fig. 9) in the following section.

Table 1. *Interactions collected during the game*

Game sessions Date Number of teams	**A 01.02.2021 7**	**B 08.02.2021 7**	**C 24.02.2021 7**
Number of interactions part 1	650	590	666
Number of: Individual actions (protect, hunt, catch) cooperation (trade)	 48 14	 42 18	 34 11

Number of interactions part 2	#	1060	1948
Number of: Investigation actions (scan and watch clue) Ecosystem actions (link between animals)	 # #	 79 60	 74 47
Number of interactions with exhibition (part 1 and 2)	102	247	270

5.3.1 *Players' interactions with the game and the museography*

Concerning the first level of interaction (the action situation) (Fig. 3), the data (see table 1) show that all the functionalities are used according to what was expected during the game-design phase. It means that the players play the game as originally planned by using the game functionalities and by interacting with the museography (see table 1 "interactions with exhibition"). For the first part of the game, this is notably reflected by the scans of the stuffed animals to collect resources for the survival of the character ("individual actions": 48 for the class A; 42 for the class B; 34 for the class C). However, the teams adopt different strategies in terms of number and selected animals and selected action (hunting, domesticating...). In addition, some teams stop collecting resources before the end of the first part which may be interpreted as they become aware that the health of the "tree of life" decreases due to a collective loss of points. For the second part of the game, the players explore the exhibition and search for clues scattered over the museum and use them to conduct their investigation (see table 1 "investigation actions"). In addition, once they have analyzed the clues, they complete the ecosystemic map which allows them to draw relationships between the different animals (see table 1 "ecosystem actions"). Based on these actions, they earn points and the energy level of the "tree of life" increases.

5.3.2 *Interactions between players*

Collaboration within the game (formulation and validation situations), which is the second level of interactions, is reflected by the trading of resources (see table 1): "cooperation actions": 14 for class A; 18 for class B; 11 for class C. Although teams were expected to trade collected resources with other teams to reduce their own energy expenditure and the depletion of shared natural resources, few trading is performed, and 3 teams do not trade any resource. We consider that it is due to the complexity and the design of this game mechanics, as well as the limited time dedicated to the first part of the game (10 minutes). However, it doesn't mean that players don't collaborate. Indeed, though the traces don't reflect the collaboration between players during the game, the interactions between teammates and the different teams are reported by the observers. In particular, they report that, in the first part of the game, some players understood the causal relationship between their actions (hunting, domesticating...) and the collective loss of points. They shared this information with other teams and stopped to collect resources. Thus, the interpretation of the collected traces depends on complementary data (videos, observations...). Here, we point out one of the limits of the interactions tracking set up during the game. The experiment protocol is now revised as we plan to collect complementary data enabling multi-modal analysis in order to reduce the subjective interpretation of the trace's co-analysis.

5.3.3 *Interactions with the game master*

Regarding the 3rd level of interactions, between the players and the game master, we observe a gap between what was planned (during the digital companion features design) and what happened. The game master makes little use of the *DigitComp* during the whole scenario. The interactions with the game master are divided into 3 phases described below.

For the 3 game sessions, the game master asked the project's computer scientist to set up the game using the default configuration, so she did not use the dedicated interface by herself. The briefing (Fig. 10a) takes place in the museum hall and lasts from 5 to 10 minutes. It is led by the museum mediator who plays the role of game master at this starting point. After reminding the audience the instructions relating to security in the museum and the use of the digital tablet, she introduces the game narrative. The entering in the game world is reinforced as she wears particular clothing (hat, down jacket, scarf) that symbolizes the harsh weather conditions that the character needs to face. This introductory phase, in plenary mode, allows the students to play the role of the character they are supposed to play. They also choose an avatar and a name. During this phase, the students become players and create teams. Interactions are limited to the narration and questions asked by the students. The game master receives the teams' names in order to identify them during the game, and once she decided to do so, she started the game for all tablets with the *DigitComp* app.

During the game, we observed that the chat room is not used by the game master who prefers to interact directly with the players. Besides, despite a conclusive pilot test (in the laboratory), the smartwatch did not work due to the disconnections from the internet network of the museum when the players move. This issue, which has not yet been solved, prevents the collection of data on physiological parameters. Furthermore, the game master dashboard (Fig. 8a) is not used during the game, nor during the debriefing though useful information is made available (Fig. 8b). The results of this first iteration enabled us to modify the game master interface based on the feedback of the museum mediator, and on the analysis of the traces collected. These modifications mainly concern the choice of data from players and a new diagram of an overview of the activity (left part of fig. 8a). This interface allows a better access to information about the game played by the teams and this information is useful for the 2 debriefings.

After each part of the game (Fig. 8b), during debriefings, the game master doesn't use her dashboard and asks players about the data available on their own dashboard. She writes the results of part 1 on a flip chart and organizes the debriefing according to a "debriefing guide" co-designed by the project team. The discussions during the co-evaluation workshop revealed that the dashboard is unattractive and that information is missing. For example, the number and the nature of the traded resources is not available for the game master. In addition, though this is an important learning outcome and crucial for carrying out the debriefing, the information about the relationships between the animals, identified by the players, are missing as well. As a result, the *DigitComp* has been revised for the next iteration in order to offer better support for the game master. The museum mediator also actively participated in the evolution of these interfaces in direct interaction with the computer scientist. However, despite of the changes and adaptations mentioned above, the mediator's discourse on the use of a digital interface in her job seems to raise another obstacle. This obstacle is linked to how digital technology changes the way museum mediation is performed. Even though the museum mediator participated to the design workshops and we offered support for the interface use, it seems that faced difficulties to leave her usual practices, thus avoiding risks of being destabilized by unexpected event and loss of control due to the use of new tools. In addition, we observed closed question, strong guidance and little room for students to express themselves freely during the debriefings. We interpret this observation as a need to keep strong control on the situation as revealed in many works about teaching practices [26].

This study remains a case study, limited to one museum mediator, however it highlights a difficulty that technical or ergonomic modifications cannot solve. Another museum mediator will soon join the project and further game sessions are planned. New data related to the use of the *DigitComp* will be collected and we will be able to assess its use with a different user.

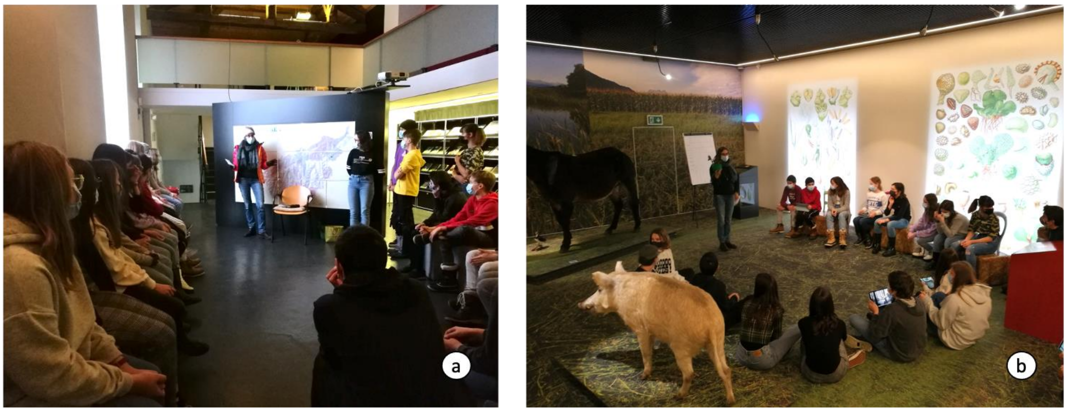

Figure 10. *Briefing (a) and debriefing (b) during the game scenario*

6 Conclusions and Perspectives

We consider the digital companion *DigitComp* as a first step towards a systematic and holistic tracking of the players' interactions and the support of the game master for the orchestration of a mixed-reality game. *DigitComp* is based on the observation of players' activity through the collection of interaction traces and functionalities enabling the game master to orchestrate the game. However, the use of the *DigitComp* changes the nature of the museum mediator tasks and adds new ones due to its functionalities. An analysis of these tasks combined with data from the game sessions would allow to automate those that could be considered as generic and repetitive in order to focus game master actions towards a more personalized guidance.

Regarding the issue about what the players did, *DigitComp* managed to capture the digital traces of the players and offers a good overview of its activity in the Museum. However, these traces capture a limited part of the players' activity and need to be completed (audio or text recordings when they solve the puzzles).

We consider that the main contribution of this paper consists of a new didactic modeling of the game-based learning situation. This model allows for the identification and the description of the different types of interactions set up by a mixed reality game. Indeed, this model serves as a basis for describing and categorizing players' activity. As a result, it offers the game master fine-grained information about what happen during the game based on the aggregation of raw traces. However, since we managed to collect useful digital traces from the action situation, collecting traces from the formulation and validation situations remains a challenge. The recording of audio data during the game is now implemented in the *DigitComp* and we will test this functionality during new game sessions.

Regarding the issue about what the players perceived, the digital traces enable the game master to know which animals were scanned in the museum. However, it is again a limited part of what they perceive since the players interact with stuffed animals without scanning them. The issues about what the players felt were not addressed due to technical challenges. However, since the first game session we have now implemented a new interface that captures epistemic emotions (happiness, frustration, anxiety…) [27] from the players. At specific moments of the game, we ask the players to drag and drop on their avatar, specific sentences about their feelings.

Regarding what the players learnt, *DigitComp* provides limited information (such as the relationships between the animals represented by a map) but we expect to define some indicators that may be useful for the game master. For example, when the players stop scanning animals during the first part of the game, it probably means that they learnt the causal relationship between the exploitation of resources and its consequences on the environment. The modeling of the players' experiences according to these 4 issues mentioned above may constitute an innovative approach for the representation of the activity of a player and the design of the game master interface.

The next project iteration has been carried out in February 2022 with 3 new classes in the Nature Museum. Additional data were collected (activity traces, videos, audio) in order to reduce the amount of interpretation for the analysis. The results of these analyses will again help to develop the game and the digital companion functions.

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