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Material and Socio-Cognitive Effects of Immersive Virtual Reality in a French Secondary School: Conditions for Innovation

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Abstract: The dissemination of innovative pedagogies in French secondary education, under the effect of both educational policies and the spontaneous action of teachers, raises the question of the socio-cognitive and material conditions of the design, appropriation, and use of a 3D VW learning space in school. To answer this question, we study the design of a learning space using a 3D VW and the interactions that emerge between the different actors involved in techno-pedagogical innovation. The case study included 22 5th grade students. The videos recorded concern the use of a scenario-based 3D VW for Mathematics, French and Second Language. The analysis of these scenarios based on co-presence, remote-learning and autonomy retrace the material and socio-cognitive conditions of a changing learning space that co-evolves with identities and the teachers' intent to create meaning within a hybridised institutional and organisational framework.

Keywords: materiality; socio-cognitive effects; secondary school; virtual reality; virtual world

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1. Introduction

In several countries, 3D virtual world (VW) technology is widely used at home by 11- to 14-year-olds to play current online video games, in which individuals are embodied as avatars in immersive environments. They are used for experiential learning [1] in various disciplines (languages, science, computer science, design, mathematics, etc.) or interdisciplinarity and to gain fundamental, applied, and professional knowledge. Since 2010, there has been a growing body of literature on the evaluation of the pedagogical uses of 3D VWs and their interest in terms of learning design and teaching practices, to better identify when and how they can be used successfully. This literature [1] recognises that, under certain conditions of organisation and learning design by educational teams, such virtual worlds, used for learning, would foster engagement and active learning in a changing educational space.

New educational challenges—mainly due to COVID-19—propose to focus on the personalisation of teaching and the adaptation to different audiences linked to the dissemination of digital tools and communities on the Internet, which seem to coincide with a renewed interest in these technologies and their accelerated uptake in education.

In France, there are more studies of 3D VW for educational purposes proposed in primary education. Few studies regard secondary education. Although there exists abundant literature on virtual worlds in education, few focus on virtual environments geared toward innovation and creativity in learning [2]. Less developed is a systemic vision of the conditions and implications of the design, appropriation, and use of 3D virtual worlds.

Considering the development of innovative pedagogy in French secondary education, we would like to identify, through this paper, the creative conditions and implications of the design, appropriation, and use of a 3D VW learning space in secondary education.

Technological and pedagogical innovation in teaching and learning implies leaving space for the creative transformation of material, social, and organisational conditions. From this point of view, the analysis of the design, appropriation, and use of 3D VW offers a vantage point for understanding the educational contributions of virtual spaces to the traditional architecture of the class, collecting evidence regarding the social and material conditions for learning.

All this considered, and based on a case study regarding a 3D VW implemented in secondary education, our general research question is:

- What are the conditions for an innovative design, appropriation, and use of a 3D VW for learning in secondary school?
- Specifically, we question the following:
- Which are the material conditions of 3D VW learning design that contribute to techno-pedagogical innovation?
- Which socio-cognitive interactions revealed by different actors—the teachers, the start-up carrying the technological platform, the students, and the researchers, including the avatars—support the design, appropriation, and use of the 3D VW for innovation?

The plan of the article unfolds as follows: a theoretical framework of innovation in education, context of the study, data collection methodology, results, discussion, and conclusion.

2. Actors in 3D VW Innovation: The Teacher and the Students' Avatars

The concept of innovation is a complex one as it has been applied to different disciplines (economics, management, sociology, educational sciences, etc.). Nonetheless, it provides an opportunity to cast an interdisciplinary eye on the issue of transformation in education and training. Pedagogical innovation, of which technologies are a part, is understood as any teaching delivered in a substantially different way from the traditional teaching practice and which aims to improve learning by creating something new, [1] based on new policies, strategies, methods, and the pedagogical practices of the actors [2]. When pedagogical innovations integrate, for pedagogical purposes, information and communication technologies (ICT), they modify teaching practices and are even seen as a real change in practice [3].

This perspective is shared by authors who seek to specify the social nature of change in an educational system where the professionalism of the teacher, isolated from his or her class, remains dominated, despite the changes, by practices centred on the inculcation of nothing more than student learning [4]. From this point of view, the use of ICT for learning purposes can bring about innovations in training or education if these technologies are seen as a break with teaching standards and knowledge, but also in a school's organisation and pedagogical management regarding previous practices. Consequently, pedagogical innovation can be studied from the individual and collective pedagogical creativity which presides over the appropriation of technologies for educational purposes, but also from the properties of the technology, which can be mobilised via the actors' organisation and educational strategies. In the following, we focus on the teacher's and the student's avatars' role in pedagogical innovation.

2.1. The Teacher's Role as Creative Scaffolding

In this context of innovation, the importance of the creative aspects of the teacher's work lies in the fact that he or she is reactive, flexible and improvisatory, comfortable with ambiguity, thinks metaphorically, and juxtaposes seemingly incongruous ideas in new ways [5].

In this sense, creative scaffolding is the teacher's action to support creative student collaboration [6]. This concept is in line with [7] work, which describes scaffolding as a central organiser of teacher action in a teacher–student co-activity whose goal is the teacher's effacement once the student gains in autonomy. Similarly, students are deemed

creative if they are able to combine the development of their imagination with the activity of collective rationalisation of the proposals resulting from creative support.

2.2. The Student's Avatar as an Educational Actor

It should be noted that educational virtual worlds come from the technology of video games such as Muves (Multi Users Virtual Environments), considered the archetype of the 'attention industry' [8]. In these video games, just as in virtual educational worlds, the avatar embodies the project of re-materialisation; it is both a carrier and included in the mechanism of empathy and distancing in support of situated learning. This is what is at play in the role of avatarisation in the learning process or even in collaboration, where the avatar offers the subject himself the image of another who is self-animated by the subject's actions. Thus, it is possible to produce, through the proactive reflexivity of the person, 'a theatre of operations' in a world where he or she is both 'actor' and 'spectator'. This vision is consistent with that of Sofia Gabrielle, for whom the theatre world represents a significant opportunity to recognise the strong presence of the bodily dimension in the creative process.

2.3. Design in 3D VW Innovation: Material and Socio-Cognitive Effects

Here, a learning scenario is defined as a set of learning sequences in which the student can be exclusively in an immersive 3D situation, exclusively in a physical space (classroom, multipurpose room, etc.), or in a mixed situation combining parts of activities with artefacts in the real world and parts in the virtual world.

The focus on the material and socio-cognitive effects of 3D VWs on learning and teaching derived from the complex cooperation between body and environment, which would agree and interact synergistically. However, this approach tends to see the environment as a phenomenon 'external' to cognitive activity. At the same time, another current suggests an approach to the environment as 'exteriority', which systematically implies taking into account a specific and multi-varied relationship of the individual to said environment. In the following, main concepts involved in the design of the 3D VW are discussed: mixed reality, immersion, and the sense of presence.

In the following sections, we focus on some aspects that combine the material and socio-cognitive effects with the 3D VW.

2.4. Material and Virtuality: Physical and Virtual Mixed Reality

Authors try to discover how physical space interferes with innovation and the capacity for innovation and they suggest innovative spaces for teaching and learning situations where the physical environment is a factor conducive to creativity and the germination of innovation [9]. Organisation theories claim that physical space can be a non-neutral ingredient in the environment via its artefacts. It can interfere in different ways with people and their interactions in training and education, particularly from the point of view of experiential learning [10]. Moreover, most innovation theories recognise an interdependent relationship between the social and physical dimensions of the interaction space and creativity. Innovative spaces are here conceived of as physical and virtual spaces [11]. They have been co-designed so as to allow users new practices for sharing and the co-construction of knowledge. However, they cannot occur without collective action in a world structured by formal or frontal teaching coexisting with administrative and budgetary reform policies, as well as with professional and career promotion policies, which may conflict with innovation incentive policies [12].

In this sense, the growing use of 3D virtual worlds by educational teams in their institutions and in many countries [13] can be questioned from the point of view of the associated change process in their social, organisational, and cognitive dimensions [14,15].

Individuals immersed in these spaces are in multimodal communication situations where remote exchange and mediation of knowledge in the physical or virtual world can hold a central place in the articulation between the physical and virtual worlds [16,17].

The term mixed reality is also put forth by [18] to give meaning to this complexity where the virtual is not opposed to the real. It would be more of a 'continuum' going from a natural environment to a virtual environment (and vice versa) via mixed reality (between 'augmented reality' and 'augmented virtuality').

2.5. Material and Virtual Sensory, Social, and Narrative Dimensions

The socio-constructivist approach in education applied to virtual worlds [19,20] discusses psychological immersion, referring to commitment. It is the result of three types of immersion in virtual worlds: action immersion, social immersion, and narrative immersion:

- Sensory immersion [21–23] allows the participant an experience to initiate actions with new and intriguing consequences that mobilise different senses (hearing, sight) or sensations (flying like a bird).
- Narrative immersion triggers semantic associations via the content of an experience between the real and the user's imaginary realm.
- Social immersion allows for rich social interactions between participants embodied by their avatars in a virtual world, thus developing the feeling of being an integral part of this virtual world. Psychological immersion is obtained by combining these different dimensions in the design. This theoretical approach is consistent with the theorisation of the avatar relationship in which the avatar, as a technical image of self-mediation [24], is potentially a transforming relationship in the process of learning: 'It is thus to bring out some of its novel properties, such as its capacity to engage the human subject in an artificial reality which acculturates him in return to the intimate springs of technology' (op. cit. p. 20).

This theory echoes the situated creativity current for which 'the brain expresses its functionality only and uniquely in that it is linked to a body located in a given physical world, populated by individuals' ([25] p. 51). In this sense, empathy has a role in the use of avatars, from the most intimate to the most social. The avatar would thus constitute a double manifesto that offers a unique means of access to the own subjectivity of the person who seizes it.

2.6. The Sense of Presence as Socio-Cognitive Effects

At the same time, for the person to have a deep sense of presence in the virtual world, the interface must become transparent and the commands implemented by the user fluid [26]. This proposition is linked to the fact that, in human activity, motor mechanisms are not limited to the brain's motor areas; they encompass the entire motor system, including proprioceptive mechanisms [27]. Thus, without this fluidity, the connection between cognitive and motor skills can remain incomplete and hinder immersion, which is characterised by the perception of the interaction with the virtual environment more than with the physical environment [28]. However, if these fluidity conditions are necessary, they are not sufficient. An appropriate script uses the educational potential of immersive virtual reality that paves the way for different types of immersion in the virtual world, as can also be the case in the physical classroom for teachers who base their teaching on heightened creativity and interactivity.

From this theoretical framework, in the following, we propose a case study with a 3D VW in a secondary school, approached from a systemic perspective to analyse the material and socio-cognitive conditions in techno-pedagogical innovation.

3. Method

3.1. The Context of the Study

The research takes place in the context of digital technology appropriation (tablets and software) in a secondary school in the town of Gap in the Hautes-Alpes. This school establishment has been a pioneer since 2011 in the use of tablets as part of a European project. The principal is also committed to a type of pedagogical management that is open to the outside world and supports the teachers' project initiatives administratively

and financially. In this sense, the school has encouraged the practice of co-intervention mobilised as part of the virtual school.

The virtual world and the online platform differ from a serious game in that they do not offer a finalised scenario. Still, it is a platform for computer and pedagogical skills (from popular education and open-source communities) and an open space to script teaching and educational activities. This virtual environment is represented in the form of islands. Appropriating this almost virgin space involves experimentation in the form of scripting via the individual and collective organisation of teachers and student users, assisted by researchers.

This support is carried out as part of a participatory action research (PAR) started in 2016. PAR critically analyses institutionally structured situations and activities (projects, programs, systems) in which people work [29]. The research is carried out 'with' rather than 'on' participants who are recruited on a voluntarily basis.

PAR requires inventiveness and a methodological, theoretical, and experiential combination adapted to the research object and its participants. This methodology, via immersion in the field, allowed us to collect various data over several years (2016–2019). In this project, the teachers' overtime for the experiment was compensated under the programme Lieu d'Education Associé LEA (a system monitored by the Institut Français de l'Éducation, attached to Ecole Normale Supérieure Lyon). Obtaining these hours was consistent with the ethics of participatory action research, attentive to the fact that voluntary participants should benefit from sufficient resources (financial, training, communication, organisational, etc.) to become involved to the extent of their ambition. The data were collected from interviews with the educational team and students with PAR researcher involvement, videos of tasks based in the virtual world, videos of students in class using their laptops to perform tasks based in the virtual world 3D, meeting notes, and e-mail exchanges.

3.2. Data Analysis

This study uses participative observation of student and teacher interactions mediated by VW in the 5th grade.

To meet the aims of this paper, our primary data sources were audio–video recordings—the other data sources were primarily used to clarify and enrich our interpretation of the material and socio-cognitive conditions of learning.

The videos are archived in a university dataset. Each video is classed with keywords. The research team is familiar with the videos considering that the researchers are involved in the collection of them in classroom and VW. The research team has also conducted the collection of interviews and complementary data throughout the project [19].

From the audio–video recording dataset, we analysed five video recordings in depth, which were selected based on the main spatial and temporal conditions of the use of VW as an innovative reconfiguration of the learning space in the secondary school:

- In co-presence: the students connect to the virtual world in the classroom and work in the VW via avatars.
- Remotely: the students are at home, and the teacher is in the school.
- Autonomously: the students have autonomous individual or collective activities in the virtual world without the presence of teachers.

The class includes 22 5th grade students. The five videos used relate to five different learning scenarios, with a VW for Mathematics, French, and Second Language. See Table 1 for a summary of the video recording sessions selected.

Table 1. Video recording data selected.

Class	Lesson	Purpose of the Use of VW
Co-presence	Math	The geographic coordinates of the map engage students in solving equations through play
	Second Language	Virtual display of their favourite places in their city to discuss with foreign students
	French	Headquarters to solve linguistic learning tasks
Distance	Math	The Math remediation learning support
Autonomy	French	Revising irregular verbs.

The video data analysis of the learning sessions started with a close review of each video to understand its structure and interactional order from the participants' perspectives. Therefore, we explored the videos, selecting relevant episodes for in-depth analysis [20]. The selection criterion was detecting innovation in learning conditions. The analytical framework of our study draws on iterative interaction analysis frameworks with a focus on material and embodied interaction [30] and socio-cognitive conditions.

In particular, to carry the analysis for each scenarios selected we focus on:

- The teachers' creative scaffolding;
- The students' creative activity;
- The avatars affordances in the use and appropriation;
- The ITC society and institutional interactions.

These factors are combined with the sensory, social immersion, narrative dimensions and sense of presence in the virtual and in presence conditions, as above described. Each dimension is marked and recognised with a linguistic and semantic index in a codebook applied to the scenarios analysed.

Finally, topical episodes were selected to carry out a detailed analysis, the findings of which will be discussed in the next section.

4. Results

To answer to our questions about the conditions for an innovative design, appropriation, and use of a 3D VW for learning in secondary school, we analyse techno-pedagogical scenarios based on the conditions considered: co-presence, remote learning, and autonomy to retrace the material and socio-cognitive conditions for innovation. Specifically, for the scenarios selected we identify the material conditions of 3D VW learning design that contribute to techno-pedagogical innovation and the socio-cognitive interactions revealed by different actors—the teachers, the start-up carrying the technological platform, the students, and the researchers, including the avatars—supporting the design, appropriation, and use of the 3D VW for innovation. The three scenarios analysed became the unit of analysis to answer to our research questions.

4.1. In Co-Presence: Innovation in the Design of the Learning Tasks

The Math teacher in the 5th grade used the VW for a learning activity on how to solve equations. In the Math learning scenario, the teacher uses the geographic coordinates of the map to engage students in solving equations through play. Here, the virtual world is a learning support insofar as it combines algebra and space geometry through a pragmatical use of the spatiality of the virtual world to anchor the concept of the equation.

The virtual school has several locations (medieval castle, language space, pirate port, etc.). All these locations and all the places registered within (tents, houses, panels, constructions . . .) are defined using X, Y, and Z coordinates, namely, abscissa, ordinate, and height.

The course is scripted in the form of a challenge. The teacher (Mathias) asks the students to solve two equations with one unknown whose results correspond to the X and

Y coordinates that will be transferred to the virtual school on an interactive map. The Z coordinate corresponds to height; the teacher gives it although the students stay down on the ground for the moment (they can also fly). During the exercise, the teacher answers questions and helps the children as he would in a regular class. At his signal, all the students validate their coordinates. Those who answered correctly are 'teleported' to the expected location with the teacher. The others stay put or are 'teleported' to another location. The teacher (Mathias) can then locate them on a map with a radar. At the beginning of the activity, we observe that the class atmosphere is quite typical and relatively calm. But a little before the validation of the results, the teacher places the students in a challenging situation: 'Let's see who found it! And with the map, we will see who is lost'. Once everyone has been 'teleported', the teacher orally brings the students back to the physical class and resumes a traditional correction of the activity. However, Mathias stimulates part of the students' imagination to encourage them to listen 'because otherwise, you will not be able to do the second stage and you will get lost, which would be a shame given the place!'. At the end, the children will have teleported three times and solved six equations.

For the German lesson, the teacher moved the boundaries of the class to mirror how the students created a virtual exhibition of their favourite places in their city. This production was carried out with a view to a remote exchange with penfriends in the virtual world.

For the French lesson, the teacher designed an activity within the interdisciplinary projects 'Explorateurs' (Figure 1). She divided the class into various groups, each taking on the identity of an explorer. Each of them was assigned a book and several students. Various activities were carried out, such as writing a poem. The students had to share ideas through the chat. This teacher's creativity led her to ideate Headquarters (HQ) for each explorer in a location called 'Pirate Port' built specifically for this great explorers' project. Two elements indicated the location of each headquarter: a cube to which the cover of the book in question was affixed and the coat of arms of the explorer invented by the students. For each group activity, the students, via their avatars, met in their respective headquarters to exchange and solve the language learning task. The students were both in a physical area of the classroom and in a virtual location symbolising their working theme.

Figure 1. Photograph 1. In the pirate port, the headquarters of an explorer group.

4.2. Remotely: Innovation in the Interactions between School and Family

'Homework done' is a national education remediation learning support for students. In secondary school, the Math teacher decided to use it in VW. She designed her sessions. She affixed the first exercises to virtual panels(Figure 2).

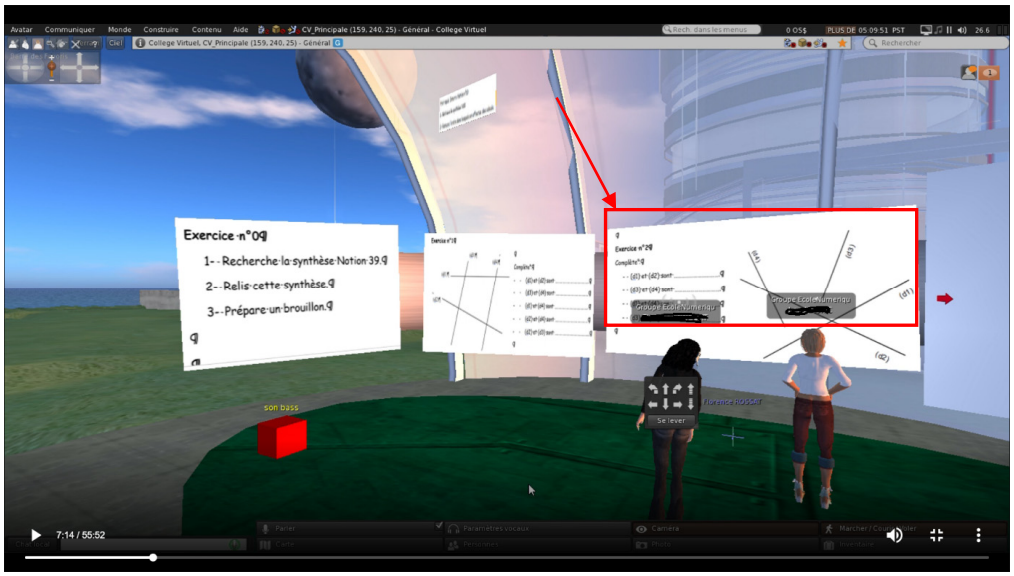

Figure 2. Students doing an oral maths exercise remotely using the virtual panels (Exercice n°29).

There is a special spatial arrangement. On the left, an organisational and methodological panel gives the student instructions to prepare the session at a content level with a summary sheet on a mathematical notion that the student has at home and that he or she must review, as well as a work support—in this case, the draft—in a mixed reality context. This allows children to connect a little before the session and prepare to work in optimal conditions. On the sides, there are various exercises meeting the students' requests. As the session progresses, the exercises are replaced by new ones.

In these learning conditions, a parent, via the avatar, can intervene during the course and in the teacher–student relationship to clarify educational points. This social immersion is instantaneous and simultaneously mediated, hence a certain informality and familiarity in speaking—as in extract n. 1:

- *Mum: I'm Lily's mum. May I ask you a question?*
- *Teacher: Yes, hello, of course!*
- *Mum: When there are quizzes on all those kilograms, are they allowed to do the table next to it?*
- *Teacher: Do it no but take the card I gave them, yes.*
- *Mum: Even during written tests ?*
- *Teacher: Like all the students, yes.*
- *Mum: Because the last time she didn't take it out, she told me that she had no right to do so, but I told her that she...*
- *Teacher: Yes, they have it all the time and take it whenever they want, even during quizzes . . .*

In another situation, the student's siblings equate an hour of homework to an hour of play and claim the use of the internet on another computer station to play online video games—as in extract n. 2:

- *Technical support: Laura, is anyone else using the internet in your house?*
- *Lola: Yes, my brother.*
- *Technical support: It won't work because you can't hear what F. (teacher's first name) is saying. Can you hear me there?*
- *Lola: No, I can't hear you.*
- *Technical support: You won't hear Tom either. It's normal; you don't have enough speed for both you and your brother.*
- *Lola: Speech is activated but in light grey. We cannot use it.*
- *Technical support: This is normal; not enough internet speed.*
- *Lola: I'll tell him and see if it works.*

Thus, in this learning scenario, the spaces are multiple and mixed between school and family. The family can enter the school system via the student's avatar. However, this is still limited to a specific space inhabited by the avatars.

4.3. Autonomy: Flying and 3D Construction

An example of the use of autonomy at home is the co-construction of a scenario with artefacts driven by two students assisted by their teacher to review irregular verbs. They staged and 'concretised' the verbs as cubes, distributed in a tree and all around a moon. The verbs around the moon represent verbs associated with night (to sleep, to get up, to dream) and those in the tree relate to daytime activities (to do, to find, to meet . . .). With each click on a cube, we hear the recorded voice of an English assistant saying the verb in the infinitive, in the past tense, in the past, and in French. Example: click one make, click two made, click three made, click four makes(Figure 3).

Figure 3. In the language space, the pupils' irregular verbs scenario with interactive building blocks.

In this learning scenario, knowledge is placed geographically in separate and symbolic places to promote situated learning, the scripting of which is designed and carried out partly at home by the students via their avatars.

Similarly, this teacher used the school to stage preparatory quizzes for a 'Big challenge' competition. Students could meet with one another on the platform to revise and prepare for this competition. The quizzes were placed on huge panels arranged in different places. These panels were made visible thanks to signage; framed by two fluorescent red columns in a larger 'language space'. To read them, students had to either fly their avatars or sit and use a zoom function. Thus, learning spaces were intertwined with the geography of places to ensure consistency in connection with the academic programmes.

Around the context of learning tasks, students have an exploratory use of the platform. This means that they take ownership of it by visiting places. To explore places, the pupils use the 'fly' function. It grants them speed of movement and the sensation of flying (sensory immersion) because they fly over the facilities and the islands of the virtual school, thus learning the geography of the places, and sometimes thwarting the teachers' scripts. They told us that they spend a lot of their time just flying. It should be noted that this 'flying' mode also works underwater. This is important because students explore the virtual world on every level (sea, land, air). They do not encounter animals or plants, but

rather constructions made by other students, which gives them the feeling that they are discovering a new world. In this sense, exploring the seabed is very popular.

Furthermore, 3D buildings, such as houses with specific textures in dedicated spaces, encourage the appropriation of places. Building is sometimes carried out outside these spaces. However, this is tolerated because it fosters the appropriation of places and the creativity of some students by inspiring others. Thus, although there are geographical places of formal learning, many places are used as spaces of creativity and intimacy.

5. Discussion

Based on our results, we looked at the material and socio-cognitive conditions for innovation with a 3D VW in the three conditions considered.

In the first condition, co-presence, as in the Math script, the interaction between the virtual world and the physical classroom creates a learning space continuity that reaches beyond the classroom walls. Academic knowledge is transmitted by relying both on the child's imagination and on the intrinsic coordinates of the immersive space. The constant back and forth between physical and virtual learning spaces helps to engage students. In addition, academic knowledge is concretised and brought back to real-life situations: a false result has real consequences. The geographical dimension assumes a form of concretisation of academic knowledge in a scenario in which the avatars are physically moved around in the various areas of the virtual school. The avatar allows the student to no longer be in the classroom and to be immersed in different places [22,23]. Thus, the teacher takes the students through the scenario and immerses them in action and narration. The social immersion is intense, as in the Second Language scripts, because there is a strong commitment to sharing virtual photos and space with outside students. The urbanisation style, the creative scaffolding of the narrative adventure, as in the French script, supports the acquisition of content and fuels the imagination.

In the second condition, remotely, the students are at home and the teacher is at the school, and there is a continuity of interaction between the physical workspace and the space enabled by the platform. The learning space is characterised by a substantial porosity between the family and the school sphere, thus opening new interactional opportunities. Because of this porosity, this learning space is also of fragile construction. The school enters the home, and the educational actors may have to limit daily activities in the home due to competition for the use of internet broadband, a room, or the computer. The students, via their avatars, move in front of the panels that show exercises corresponding to each person's needs. They sometimes find themselves alone and sometimes with others when the concept answers a request made by several students (social immersion).

In the third condition, autonomy, the platform is used to perform modalities (animal heads, wings, etc.) and test the functions that, for example, make the avatars dance. They discover these functions by chance and pass them on to friends as a collective resource. Uses at home without teachers suggest that the virtual school restores the continuity of the learning space by securing the children's imagination and their social world in a unity of place that includes symbolic and socio-material characteristics that are differentiated from the traditional school space.

Finally, we can consider the material and social cognition that support the 3D VW as innovative techno-pedagogy related to:

- The creative scaffolding (including scenario and design of artefacts), which was developed and implemented by the teachers and the pupils in a supportive setting at the level of the establishment and its partnership network. To immerse the students in their mixed scenario, teachers must develop new skills from the internalisation of class management mental schemes to implement their pedagogy [22]. For the teacher, this learning is new and delicate because it involves creating a unity of place from an ambivalent space in which teachers are faced with complex multimodalities linked to double corporeality and location: the body seated in the class and the avatar body which acts and moves in the virtual world.

- The avatars' affordances for action-oriented, social, and narrative immersive learning through different temporalities and spatiality, in class at school, remotely at home, and out of class at home. In this perspective, we consider the performative effects of the avatar relationship in a VW in social proximity between teachers and students and between students in and outside school [28,31]. Moreover, the teacher's relationship to the avatar and management thereof creates the continuum between the real and the virtual environment for various uses and transforms the learning space.
- The urbanisation of a multi-user virtual environment which emerged from the co-designed engagement between the teachers, the start-up carrying the technological platform, the students, and the researchers. This continuity offers the possibility of inhabiting the school space differently, with the urbanisation of the virtual school transforming the mental representation of the school and class space. The interdisciplinary and complex arrangement of actors [32], online technology, and content (researchers from two universities, companies, and foreign educational establishments) relies on renewed pedagogical management, providing material, organisational, and financial resources by the project. Such management appears to be a factor of efficiency in education, according to authors such as [4]. The proactivity shown by the principal and the coordinating teacher in terms of pedagogical management, as well as the assistance of researchers and of the start-up, have fostered individual and collective on-the-job learning through the initiatives and the creativity of the teachers, without whom technology would not make any sense.

6. Conclusions

The various scenarios analysed show evidence of the material and socio-cognitive conditions to transform the physical space of the classroom, thus fostering innovation in education. The study's limitations is that is it focuses only on some of the scenarios developed in the broader project.

This study also has implications in terms of the teacher competency framework in a post-pandemic society. Additionally, it points to a localised systemic transformation in educational organisation and spacialisation led by a team of teachers cooperating with the school director in a broader collaborative project logic which involves the university and territory in the building of a hybrid learning space able to: fuel the teachers' and the pupils' imaginations, create substantial porosity between the family and the school sphere, recreate a unity of place that includes symbolic and socio-material characteristics differentiated from the traditional school space, such as the social form of teachers' authority. The professionality model put forth in this project is a hybrid model [33]. This model articulates two separate perspectives on the political and strategic references of organised educational action, namely: managerial professionality and collegial professionality. These interact in the localized innovation process to enable meaning-making through new differentiated professional knowledge and identities within the local collegial community of teachers.

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