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Immersive Learning Experiences for Understanding Complex Systems

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Abstract. Complexity is core part of our lives. Aware or not, people need to understand and communicate complex ideas and perspectives. Understanding and communicating complexity can be facilitated through interactive simulations. Doing so in the physical world is often impractical, however. Users and developers are overloaded with information and ambiguity, costs are prohibitive, and unsupervised physical simulations raise safety concerns. Novel immersive technology might hold the key to transforming how we tackle understanding and communicating complexity. In this position paper, we propose empowering user agency and perception to take part in complex learning experiences and create their own, combining two factors: enhanced visual and spatial context provided by location-awareness, immersive environments, and somatic, embodied agency; and enhanced cultural and social context by leveraging as input methods the rich semantics of cultural-social gestures and rituals. To deem the feasibility of this argument, we propose developing two culture-aware prototypes, one for the Confederated Salish and Kootenai Tribes in Montana, United States, and another for a Western Europe cultural context.

Keywords: Complexity · Complex systems · Complex learning · Immersive environments · Emergence · Culture · Context · HCI · Gestures

1 Introduction

Stephen Hawking once said he thought the 21st century would be the century of complexity [5]. The world is an extremely complex place and has been rapidly evolving for some decades, comprised of complex and interconnected systems, creating novel challenges that call for a new way of thinking. Ecosystems, societal issues, politics, weather, and the human body are examples of such complex systems. They are complex – not to be confused with chaotic – in the sense that

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they act in interdependent and unpredictable (non-deterministic) ways. A key concept that makes complexity diverge from chaos: emergence. Simply stated, some features that emerge in large systems cannot be traced down to lower components, causing uncertainty to be inherent. Examples of such properties are the behaviours of water or of a bird flock. Even if initial conditions of individual birds or water molecules are known, the behaviours seen afterwards – of the whole – cannot be predicted directly (*e.g.*, flight formation, surface tension); rather, they have emerged from interactions of individual system components. Complex systems, or the study thereof, may hold the key to our understanding in this regard. Complexity science replaces the reductionist paradigm with a more holistic approach. Thus, the process of learning about complexity, which the literature traditionally calls Complex Learning [10,13], poses specific challenges.

This paper argues why Complex Learning and its challenges might be eased through the combined used of immersive environments and context-aware, culturally-leveraged learning experiences. It concludes by outlining a proposal for subsequent validation of this idea, developing two immersive learning experience prototypes, one for the Confederated Salish and Kootenai Tribes (CSKT) in Montana, United States, and another one for a cultural context in Western Europe. The expectation is that users, through these prototypes, are empowered to understand and communicate complex concepts and ideas.

2 Complex Systems

There is no single, formal definition of complex systems. Complexity, by itself, has several definitions proposed by authors with different backgrounds, objectives, and research perspectives, which led us to reflect on its interdisciplinar nature. Apparently dissimilar systems can share important commonalities both in structure and behaviour, so it should be possible to find universal or more fundamental laws by which their properties are governed [11]. Emergence is often described, originally by Aristotle, as "the whole is something besides the parts" [2]: the collective phenomena at a higher level are not the simple sum of the individual behaviours or characteristics of the constituent elements – a composite whole [6]. This is also called synergy, such as the division of labour of the ants or sounds' destructive interference. Complexity is associated with the intertwining and inter-connectivity of the constituent elements of a system and the surrounding environment [8, 11]. By extension, the definitions of complex systems [6,8,10,11,21,23], typically based on ideas from authors such as Holland, Funke, and Dörne, agree that a large number of elements, interacting at various levels, result in the emergence of a new level of organisation: self-organisation. Thus, there is a hierarchical structure with all these levels effecting each other. They are interconnected and interdependent on each other, and it is not possible to completely isolate a whole system or reduce the whole thing to one level. The very emergence of order, out of apparently chaotic or noisy behaviour is a manifestation of complexity. The coexistence of order and noise and their interweaving appearance is the complexity. Thus a complex system is a spe-

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cific type/class of system with properties that lead to emergence, namely: *(a)* multiple constituent elements, relations, and levels of hierarchy; *(b)* exhibiting non-linearity and phase transitions, that is: joining two things does not necessarily mean that the result is simply the sum of the properties of the individual elements, and occasions where a minimal change of a value, through feedback loops, can trigger large systemic effects [11]; *(c)* connectivity, as a driver of complexity, meaning the system's is topologically a network; and *(d)* autonomy, variability, and adaptation, as enablers of self-organisation and evolution.

3 Complex Learning

Learning is nonlinear, adaptive, and constructive [6] – indeed learning is itself a complex process. Therefore, learning about complexity is the application of a complex process (learning) to a complex concept (complexity). The resulting hypercomplex system is thus a challenging and distinctive social cognitive process [10]. This nature has traditionally been expressed in the literature as "complex learning", despite its ring of pleonasm.

Little wonder then that teaching complex concepts is challenging for teachers, communicating complex concepts and ideas is challenging across intercultural contexts, and even societal clashes may arise from lack of common understanding. Several efforts have been carried out attempting to understand and explain the phenomena. One particular aspect is that often teachers cannot put themselves in the cognitive status of the novice student, no longer remembering the difficulties themselves faced when learning the same topic. This is called the curse of knowledge bias or hindsight bias [9]. In this regard, Ifenthaler argues [10] that effective learning environments for complex knowledge domains should target three attributes: *(a)* understanding complex systems; *(b)* developing adaptive expertise; and *(c)* acquiring soft skills such as collaboration (*e.g.*, peer-learning– to tackle the aforementioned curse), communication, and task coordination. The literature on this problem includes learning theories such as Complex Constructivism [6] and Connectivism [20]; instructional strategies such as the 4C/ID model [13] or the Complex Problem Solving (CPS) process [8]; and focused aspects such as the aforementioned hindsight bias or the importance of feedback and repetition [22].

These proposals hinge on planning and providing circumstances and processes within the context of learning environments in support of complex learning, where the learner interacts (exerts agency) and perceives the outcome. The underlying perspective is that our personal mental models, states, constructs, or entities (depending on the theoretical lens on knowledge) change, not only by self-reflection and inner interactions over time, but by interaction with the physical world. Our agency and perception in this interaction are heavily influenced by prior knowledge and worldviews (dependent on social interactions and culture). The outcome then impacts subsequent agency and perception.

However, providing complex learning experiences/interactions in the physical world is often infeasible. Not only due to monetary issues or the risk they may

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entail (*e.g.*, simulation of catastrophes/accidents), but also because of their dynamic complexity, the presence of confounding and ambiguous variables, and the fact that feedback is often misinterpreted or surfaces with a time delay. If this occurs, the number of iterations of these cycles decreases and consequently slows the entire learning process, including the ability to accumulate experience, test hypotheses and improve [22]. Back in the early 80s, Papert and Schön suggested a way they deemed feasible to carry out and create such experiments, through simulation spaces or virtual worlds. According to these perspectives, the main benefits of using immersive learning experiences (*i.e.*, virtual, augmented, mixed and cross reality, in present terminology) in the field of complex knowledge, are: *(a)* the removal of aspects that are peripheral to the experience, isolating it the most; and *(b)* having greater control over the variables, so that the learner can exert agency with complete, accurate, and immediate feedback. One such example was presented by Ifenthaler [10], and combines the benefits of mobile learning, virtual learning environments and augmented reality.

4 Learning in Context

Though often overlooked as trivial or shared common ground [19], context shapes learning through the surrounding environment, particularly through social interactions and culture [22]. It is also considered one of the challenges of complex learning due to its situativity in real life contexts [10]. Virtual learning environments from complex concepts should thus leverage the context of the surroundings (*e.g.*, physical, social, cultural) – becoming situated learning environments. Technology can enable interaction with culturally-rich social immersive environments [7, 10, 16, 19] but this also leads to new challenges concerning their use, design and development. Currently, such environments are not authentic contexts for most everyday complex situations. This occurs for numerous reasons; from immersive environments not being tangible (for the most part) to failing to reflect the importance of the social dimension [7]. To tackle these challenges different authors [3, 7, 10, 19] propose methods, models, and recommendations for analysis, design, and engineering of context, combining technical dimensions with cognitive theories and educational processes. The challenge of tangible interaction in particular has seen a recent spike due to wide interest in gestural input modalities in mobile devices, the so-called natural user interfaces (NUI), leading to renewed interest in the wider approach of multimodal interaction. The "natural" allegation of NUIs has been criticised, due to the high level of artificiality it entails [12] and even for the fact that most such "natural" interfaces do not follow basic principles of interaction design [17]. They imply the learning of a set of predefined gestural commands by users – rather than the other way around, *i.e.*, the interfaces accepting whatever commands users would already deem "natural". For instance, one can consider the interaction with current head-mounted devices such as HoloLens, Oculus Rift, HTC Vive and, more recently, Magic Leap. Switching between these devices typical interfaces requires learning different arrays of gestures/commands using one's hands or joysticks.

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This ignores the cultural and social dimensions of context. The proposal below establishes a relation between human-computer interaction studies and anthropology, leveraging it to make systems that are more context-aware. Previous studies [1, 14, 15] present preliminary contributions on the potential and feasibility of creating a cultural layer abstracting the interaction processes and elements (*e.g.*, gestures and other somatic aspects) from its system control effects (commands) – the shamanic interface. Critically, recent results point towards the use of cultural-aware gestural emblems for interaction resulting in better remembrance and lesser command input errors than using gestural emblems that are not cultural-aware [4].

5 Proposal and Future Work

The proposal herein is part of an ongoing research effort with the overarching goal of empowering non-experts to understand and communicate systemic concepts and ideas.

We hypothesise that a significant contribution can be achieved by an innovative combination of two factors: *(1)* enhanced visual and spatial context provided by location-awareness, immersive environments, and somatic, embodied agency; *(2)* enhanced cultural and social context by leveraging as input methods the rich semantics of cultural-social gestures and rituals.

The expectation is that a computation system tapping this combination will enable users to understand complexity better, by exerting agency and perception within the enhanced visual-spatial context, exploring the interconnected concepts and data. The enhanced socio-cultural context of input methods aims to support more powerful and diverse semantics for that agency, thus contributing to a deeper perception and from there, better *understanding*. And that non-expert users can better *communicate* their complex concepts and ideas, due to being empowered by the more powerful semantics of agency and the enhanced visual-spatial context, and thus create representations of those ideas that are dynamic experiences in their own right, which can be explored by third parties. To appraise the feasibility of this proposal, leveraging early results aforementioned [4], we plan to develop two cultural-aware immersive learning experience prototypes, one for the cultural context of the Confederated Salish and Kootenai Tribes (CSKT) in Montana, United States; and another for a cultural context in Western Europe (yet to identified). Besides serving as validation artefacts and constraints for the concrete rendering of this proposal, the complex concepts communicated by the dynamic experiences created by the users can be explored mutually and contrasted with the level of understanding achieved via more traditional means. The basic concept for the CSKT prototype stems from a story told by a Pend d'Oreille elder, Luli's Journey [18], about Canadian geese migrations. The goal is to empower users to *understand* the emerging nature of the geese V-shaped flight formations (*i.e.*, complex flight dynamics), and for them to *communicate* the insights people obtained in the past from observing the birds (*e.g.*, weather patterns)–see Fig 1.

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Potentially, extending it to wider topics such as climate change and its effects on the food chain, urban planning, ecology, entrepreneurship, psychology, among others. Following the rationale above, the CSKT prototype should use immersive technology and somatic interaction in the visual-spatial context of the Flathead Indian reservation (*cf.*, *factor 1*), and enable interaction through sociocultural-aware gestures and emblems. *E.g.*, switching to bird's eye view using a 'sky' gesture or changing the current season between winter and summer, reflecting that through landscape changes within the immersive environment (*cf.*, *factor 2*).

Fig. 1. Sample illustration on flight formation from Luli's Journey [18].

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