Chapter XII
The Path between Pedagogy and Technology: Establishing a Theoretical Basis for the Development of Educational Game Environments

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ABSTRACT
The power of computer game technology is currently being harnessed to produce “serious games”. These “games” are targeted at the education and training marketplace, and employ various key game-engine components such as the graphics and physics engines to produce realistic “digital-world” simulations of the real “physical world”. Many approaches are driven by the technology and often lack a consideration of a firm pedagogical underpinning. The authors believe that an analysis and deployment of both the technological and pedagogical dimensions should occur together, with the pedagogical dimension providing the lead. This chapter explores the relationship between these two dimensions, and explores how “pedagogy may inform the use of technology”, how various learning theories may be mapped onto the use of the affordances of computer game engines. Autonomous and collaborative learning approaches are discussed. The design of a serious game is broken down into spatial and temporal elements. The spatial dimension is related to the theories of knowledge structures, especially “concept maps”. The temporal dimension is related to “experiential learning”, especially the approach of Kolb. The multi-player aspect of serious games is related to theories of “collaborative learning” which is broken down into a discussion of “discourse” versus “dialogue”. Several general guiding principles are explored, such as the use of “metaphor” (including metaphors of space, embodiment, systems thinking, the internet and emergence). The topological design of a serious game is also highlighted. The discussion of pedagogy is related to various serious games we have recently produced and researched, and is presented in the hope of informing the “serious game community”.

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INTRODUCTION

The use of computer game technology, especially the deployment of commercial game engines such as Unreal Tournament 2004 (UT2004) is becoming an established activity with ‘Serious Games’ research projects. Despite these projects, there has been little attempt to develop a theoretical basis for the production of educational and training immersive environments (IEs). In this chapter we discuss our approach to establishing a theoretical basis for the construction of Serious Game IEs based upon pedagogical principles. The domain discussed in this paper refers to physics education, though our research has included other domains such as software programming, education of architects and artists, and training of police officers. In this section we establish a correspondence between the various affordances of the game engine and associated pedagogical principles. In subsequent sections we discuss several pedagogical principles which map neatly onto game engine affordances. Within a discussion of (i) non-collaborative, i.e. instructional and autonomous learning and (ii) collaborative learning, we highlight approaches derived from Concept Maps, Experiential Learning Theory, Adaptive Learning and the socio-cultural theory of Vygotsky. Within (ii) we apply theories of collaborative learning based on the cognitive approaches of Dillenbourg, discourse analysis and contemporary dialogic theory according to Bakhtin. Theoretical approaches are juxtaposed with a discussion of the practical affordances of the UT2004 game engine. Many, but not all of our theories and design principles have been tested in various IEs, yet we believe that a theoretical approach, as suggested here, may be of great use to educational game developers. There is of yet, no ‘theory’ of computer games, since the discipline is too young, there is insufficient material to be subject to a scientific analysis and therefore to the establishment of a theory. The design of computer games is grounded in principles which have been informed by classical (e.g. board) games, as well as the digital technology which supports the development of commercial games.

An example of an IE created with UT2004 is shown in Figure 1. Here, in this room, two learners and an instructor are engaged in collaborative discussion about a physics experiment involving objects, shown as spheres, which move under the influence of gravity with or without the friction provided by air resistance. Each person has ‘logged in’ through an internet connection to the game engine supporting the IE. The engine faithfully represents the motion of the objects (through the physics engine component). Collaborative learning is supported through spoken communication; each person has headphones and a microphone. Through discussion they may negotiate which experiment to perform and how to perform it, setting parameters and analysing logged data. This room is connected to other rooms where additional approaches to learning about gravity are explored. Further rooms explore additional concepts associated with this aspect of physics. This structure provides a rich learning environment which supports linking of concepts, attention to individual learning styles, and approaches to collaborative and adaptive learning. This chapter explores theoretical approaches to aid the construction of such rich learning environments.

Figure 1.
We suggest that the generation of educational materials must be grounded in theories based on pedagogy and not solely driven by contemporary technology. There is a clear dialectic here which must be resolved. As a first step in addressing this, we have aligned ‘affordances’ of computer game technology (the tools and game elements available for use) and have set these affordances alongside pedagogical principles; the result of this mapping is shown in Table 1.

The affordances have been divided into several sections. In (a) we consider the IE as a whole, i.e. a network of rooms containing interactive elements. How do we design the layout or ‘topology’ of this network of rooms? This is the first question for an IE designer. The entire IE can be considered as an analogue of the physical world. Behaviour within the IE is close to that observed in the physical world, but of course not identical. This is a strength; an IE can be constructed to contain the desired learning experiences without any distracting information. For example in physics experiments friction can be turned off, which simplifies the study of motion. This is not easy to do in a laboratory setting. Also, learning within an IE is experiential driven principally by the learner’s experience of phenomena. This suggests we must take on board theories of experiential learning. The topology of the IE (which rooms are connected to others and why) must be considered. As we explain in detail below we use the spatial metaphor to link the IE topology to the knowledge structures of the expert educator. Each room is associated with a subject concept (e.g. friction) and is linked by passageways to other concepts (e.g. falling under gravity). As the learner journeys through the IE rooms, he/she is effectively traversing the knowledge structure of the expert, thanks to this spatial metaphor. IEs may contain a single learner, who therefore learns in an autonomous mode, or else via the internet which may contain several learners allowing for guided or collaborative learning. In (b) we consider the dynamics of the game engine in the broadest sense of learner-IE interaction. On a short time scale we identify with the dynamics of experiential learning, e.g. a movement around the four states of the ‘Kolb cycle’. On a longer time scale we identify with the dynamics of adaptive learning where the IE may change as a consequence of the learner’s actions. Various technology components are listed in (c). Of importance here is sound which supports the use of the spoken word. This may be used to establish a narrative, storytelling, discourse and dialogue. In (d) the interaction between learner and IE objects is provided by the console and Heads-Up-Display (HUD). We have programmed many HUDs to display e.g., the current parameters for a physics experiment or even the results of that experiment. This provides another dimension of learner-IE interaction. The functionality of an IE based on a commercial game engine can be extended by programming. In (e) we identify three areas where this has been done to increase the functionality of our IEs. We have programmed physics actors to solve mathematical equations (e.g. the Lorentz equations), and to display the results as objects located within the IE and to log their state to a text file for further analysis. We have programmed NPCs to act as ‘guides’, leading the learner through the network of concepts and activities contained within the IE. The learner is embodied in the IE as an animated character; the learner may choose either a first or third person view of the IE. This avatar has been programmed to log the player’s state (such as actions performed, test scores), as well as to manipulate learning objects, such as picking up words to assemble into text or controlling physics experiments.

As already mentioned, the technology associated with our IE worlds provides an analogy of our experienced physical world, though not in exact detail. Indeed it is the lack of detail (or ‘noise’) which makes these IEs so attractive in education; there are few ‘distracters’, extraneous influences which reduce the educational efficiency. But what is the fundamental characteristic of an IE which
Table 1. This table provides a mapping between the affordances of the game-engine technology we have used in the production of IEs (left column) with associated pedagogical principles (right column). The centre column is a bridge, asserting the ontology or the metaphor we invoke.

<table>
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resonates with education? The fundamental nature of an IE is that it is experiential, where learning results from a direct engagement of the learner with the environment through reciprocal influence and change. An IE contains buildings or rooms which the learner may explore, activities to initiate and to observe, and opportunities to converse with other learners, teachers and programmed non-player characters (NPCs). The fundamental characteristic of such IEs is experience. As a starting point to construct a theoretical basis for the construction of IEs, we have therefore embraced Experiential Learning Theory (ELT) as proposed by David Kolb, (Kolb 1984).

We have tried to establish a ‘middle ground’ between the affordances of game/IE technology and pedagogical principles, either directly or through metaphor. Two significant metaphors have emerged. The first is the metaphor of space which relates to the topological structure of the IE; a network of locations (often rooms) connected by passageways, doors or paths. The second is the metaphor of time which captures the interactive, dynamic aspect of the IE. Interactions may be reactive (such as shooting) or more strategic (such as making a detour to pick up assets). Strategic actions are guided by game rules and goals where the player is either explicitly moved towards a goal, or where the goal is discovered through play. Non-player characters (NPCs) imbued with some degree of artificial intelligence (AI) also interact with the IE, the player and other NPCs.

It is interesting to note that our chosen starting point of ELT as exemplified by Kolb’s theory of learning, which is “the process whereby knowledge is created through the transformation of experience” (Kolb 1984) picks up many of the correspondences noted in Table 1. He states that (i) learning is a process and not an outcome, (ii) it is grounded in experience, (iii) it requires the learner to resolve dialectically opposed demands, (iv) it is a holistic process of adaptation to the world, (v) it requires interaction between the learner and the environment and (vi) it results in

the creation of knowledge. Concerning (i) our IEs support learning as a process through interaction of learners, assets and other learners within the IE. Learners may, for example, make experiments concerning gravity, observe phenomena, and change parameters. Concerning (ii) our IEs are constructed in close analogy with the physical world. (iv) Learning is the most fundamental way in which the human adapts to the changing world, afforded within our IEs which provide a reduction in complexity. (v) Here the learner responds to the environment (e.g. by observing a projectile) and the environment responds to the observer (when he or she changes the value of gravity). (vi) Creation of knowledge is obtained as the learner moves through the spatial metaphor of the concept map, which is derived from the knowledge structure of the expert teacher. The learner’s concept map is not a static object, but is dynamic; it grows as the learner learns.

Our goal in this paper is to reflect on the matter of various subject domains which include pedagogy, the affordances of the UT2004 game engine, and philosophical reflections. The approach is theoretical; there is no reference to formal evaluations of our theory, but we provide substantial grounding in our designed and deployed IEs. We present a synthesis of educational theory and the results of constructing IEs to test these theories. Such a synthesis of theory and experiment is important to advance research in this area. This chapter is organised as follows: First we consider non-collaborative learning (instructional, teacher-led or autonomous). Second we consider collaborative learning. Further sections discuss metaphor and topology.

NON-COLLABORATIVE LEARNING

We define non-collaborative learning as learning situations which involve just one learner. These situations may involve direct contact with a teacher, such as in a ‘lecture’ or consist of autonomous
learning activities where no teacher is present. We have addressed the issue of non-collaborative learning through the development of a new instructional medium called ‘UnrealPowerPoint’ (UPPT). Here, PowerPoint slides are embedded within an IE in a novel structure; details are provided in Price (2008). Rooms within the UPPT may contain a number of PowerPoint slides, but are connected in a non-linear (i.e. non-sequential) manner which liberates the teacher from the usual sequential mode of PowerPoint presentations. The teacher may choose a particular path through a set of slides according to the real-time needs of the student group. For example, when students indicate a good comprehension of the presented material, the teacher may choose to enter rooms containing supplementary activities, or where students indicate uncertainty, the teacher may choose to enter rooms containing supporting or remedial material.

**Structures for Learning: Concept Maps**

One approach to modelling the learning process is to posit the existence of knowledge structures, complex inter-related networks of concepts linked by relationships which exist in the minds of both novice and expert. Such structures are referred to as ‘concept maps’ or ‘semantic networks’. Here, learning involves a transformation of the naïve concept map of the learner into the expert concept map of the teacher (Kinchin and Alias, 2005). Concept maps were introduced by Novak while studying children’s development of science knowledge (Novak and Musonda, 1991). They form a graphical representation of concepts and their relationships in a hierarchical manner. A typical example from the study of motion under gravity is shown in Figure 2.

Such a concept map could inform the topology of the IE. For example, first the concept of ‘free-fall’ (of an object) without friction could be explored through experiments and reflection located in several IE rooms. The learner could then walk into the ‘concept of gravity’ room or into the ‘concept of free-fall with friction’ room. In each case, experiments, questions and other material would be encountered. As the learner makes this journey, there is a progression through concepts of increasing order.

*Figure 2.*
Here we invoke the spatial metaphor: Our IE rooms are constructed to contain concepts, relationships between concepts are built as passageways. As learners move through the IE rooms, they are effectively traversing the knowledge structures of the expert and may therefore be able to assimilate these structures since they are presented in an experienced spatial arrangement. The transformation from naïve to expert maps is progressive; at every stage it applies the observation of Ausubel who stressed the need to consider a priori knowledge in the learning process (Ausubel, 1968). Concept maps may change as the learner learns by: (i) addition of new concept nodes, (ii) pruning of incorrect concept nodes, (iii) addition of new links between concepts, (iv) pruning of incorrect links between concepts.

The Dynamics of Learning: Experiential Learning

Learning is a process, which implies the need for a temporal dimension in the IE. One may view learning as situated between the two poles of either having an ‘outcome’, or being an ‘activity’. Lewin saw learning as changing the psychological attributes of the learner, James and Dewy saw learning as generating ‘meaning’. In either case, learning implies movement, a dynamic. Watson sees learning as producing a change in behaviour. Kohler and the Gestalt psychologists see learning as an activity. Between these poles, resides a ‘middle ground’. Piaget sees learning as establishing a structured system, balanced in equilibrium. The experiential learning theories we invoke also sit in this middle ground, combining a learning dynamic with spatial knowledge structures. Yes it is the dynamic dimension of ELT which we find so appealing. Kolb proposes a four-stage cycle in his ELT (Kolb et al. 2000).

Kolb’s central idea is that learning involves both a formation of a representation of experience (which he calls ‘grasping’) and a transformation of that experience. He sees grasping as located between two poles, one of apprehension corresponding to unquestioned experiences (e.g., walking through a forest), and one of comprehension where we produce meaningful symbols for our experiences. Comprehension turns the chaotic flow of sensory experiences into order which we can symbolise, communicate and discuss. Transformation of experience into knowledge defines the process of learning. Such transformation is continuous, iterative. This is emphasised by Lewin’s conception of learning as transforming desires and feelings obtained through experience into knowledge which informs purposeful action. Piaget also emphasises transformation in the development of the child from birth to the age of 16. Kolb sees transformation also as located between two poles; one is internal reflection and the other is active experimentation with the real world. This agrees with Piaget’s notion that action is the key to learning, that intelligence is shaped by experience, (which implies action). In the active process of learning, the learner grounds and extends his or her ideas and experiences obtained through contact with the external world through an internal reflection on these ideas and experiences. There is an outward movement of experience but an inward movement of reflection.

Kolb’s learning cycle captures this structure and dynamic. He places the two dimensions of grasping and transformation as axes on a graph (see Figure 3). Each axis is to be understood as representing a dialectic of opposing tensions, where this dialectic is resolved in the process of learning. Both Lewin and Dewey view learning as a dynamic and iterative process, moving in a clockwise attractor between the four poles on this graph.

We may conceive the learner to start at the top of this graph, in a state of concrete experience which means an observation of the phenomena resulting from a particular experiment. Moving clockwise, the learner enters a state of reflective observation which means collection of data associated with the experiment. Then, in a state of
abstract conceptualisation the learner will take the observation and the data and start to form a hypothesis which can explain these, through the invention (or discovery) of a conceptual basis. Finally in the state of active experimentation the learner will test this hypothesis through a modification of the experiment, e.g. by changing experimental parameters.

These stages are built into an IE as a group of four connected rooms. The global IE topology would therefore consist of a set of room clusters where each cluster discusses a particular concept, with each cluster providing four rooms as a metaphor of the four stages in Kolb’s cycle. Taking our example of learning about gravity: (i) In the first room, a laboratory, the learner has a concrete experience through observation, e.g. of a falling object or of a projectile. (ii) In the second room, the learner is guided into a state of reflective observation by text panels, narrative or images which encourage him/her to decide on how to collect. (iii) The learner then moves into the third room of abstract conceptualization where text, narrative or conversation helps the learner relate their observations to the abstract concepts of physics theory (such as gravity fields) and so construct individual hypotheses, and finally (iv) In a room of active experimentation where they test out their hypotheses by e.g. changing system parameters such as the strength of the gravity field or the mass of the falling objects. Moving between these rooms, guided by conversation or narrative (perhaps provided by an NPC), the learner hopefully will converge to an understanding of the particular concept. The guiding NPCs will support the iterative nature of this process by providing an increasingly detailed narrative. The NPCs are also programmed to help the learner to ‘resolve the dialectic tensions’ by posing questions and suggesting various actions.

Adaptive Learning

Since the epoch of ‘Computer Based Learning’ (CBL) there has been much interest in the generation of programmed learning materials which are tailored to the needs of the individual learner (Brusilovsky, 1999). Here the interaction and progress of the learner is monitored and is directed through the learning material accord-
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ing to individual needs. For example, hints and supporting examples would be presented when the system recognized that the learner was in difficulty. A recent classification of approaches to adaptation is found in Burgos and Specht (2006). We have used this classification to develop several adaptive IEs: (i) Learning-process components which are adaptable. Here we have constructed IEs containing doors which open into other rooms on successful completion of a test, or in response to requests for help. For example, doors leading to the study of gravity with friction remain locked until there is evidence that the study of gravity without friction is mastered. (ii) The learner model provides information useful for adaptation. We use a simple differential model which rates progress against targets, to provide adaptation through opening of doors to remedial or additional work, or to the next concept cluster. (iii) The system must gather information to direct adaptation in real time. We have successfully programmed a ‘history’ actor which records the activity of the learner, such as time spent in each room, the number of experiments attempted, the number of times an experiment is repeated, and the changes in parameters the learner has made. There is evidence that adaptation is facilitated by certain environments. Bereiter and Scadamalia (1993) make the distinction between first-order environments where adaptation is focussed on fixed goal conditions, and second order where each learner has to adapt to the progress of other learners. Our IEs are more aligned with first-order environments, where each learner is treated as an individual, even when working in a collaborating group.

COLLABORATIVE LEARNING

For a definition of collaborative learning we refer to Johnson and Johnson (2006), and also to Slavin (1997) who see collaborative learning as a dynamic process where individuals participate and where knowledge is constructed through social and intellectual interaction with both peers and experts. Dillenbourg (1999) characterises four dimensions of collaborative environments: (i) the situation, (ii) the interactions (iii) learning mechanisms (iv) the effects. The situation refers to the mix of learners; collaboration is more likely in a fairly homogeneous ability group. Types of interaction include negotiation and instruction which are effected within our IEs through the use of real-time verbal communication. Collaborative learning mechanisms include, e.g., ‘appropriation’ where the learner re-interprets his own action in the light of the ensuing actions of the other learners. During the 1990’s there emerged a criticism of contemporary educational thinking arguing that the focus on the individual learner neglected the social and cultural aspects of learning (Vince 1998). It was at this time the social learning theory of Vygotsky (1978) was highlighted, (see Holman et al., 1997). This changed the focus of the individual’s learning process, from one of learning as an individual from resources, to one of learning from resources within a communicating group, and ultimately to one of learning from peer perceptions. Computer-supported collaborative learning (CSCL) is emerging as an important type of computer mediated education following on from computer assisted instruction (CAI) and computer-based instruction (CBI) models. The tenet of CSCL is that learners’ performance will improve through peer communication, reflection on choices made and shared activities. The underlying theory draws on elements of Piaget’s social constructivism, Vygotsky’s socio-cultural theory and situated cognition, (Wang et al. 2001). Cognitive theories were initially intended to model the individual’s mental process, yet they now emphasise the socially distributed nature of cognition, (Norman, 1993). Distributed cognition is the process of sharing cognitive resources as an extension of individual resources and so to complete a task an individual would be unable to do. Such processes can be distributed between
learners or learners and machines. According to Norman, human cognitive resources have always been overestimated; the external world and fellow learners can increase these resources. Also, through social interaction, the learner is forced to see his or her conceptualisations from another point of view. Socio-cognitive conflicts have been shown to increase the learners’ cognitive resources, (Pontecorvo and Paoletti, 1989), though it is unclear whether conflict is necessary to enable collaborative learning.

Such approaches must be borne in mind while constructing educational IEs. Working with our students in various classes, including ‘OOP (Java) programming, IE/Game development, Modelling and Simulation, we have become aware of the power of teamwork in effective learning. Our students have produced ad-hoc collaborative groups which were neither required nor assessed. Within these groups, they have clearly displayed a strong desire to work in a ‘distributed intelligence’ mode. Their assessments reflect this in an honest and transparent manner.

Game engine technology provides collaboration for free: several learners may enter an IE synchronously over the internet. Each is equipped with a headset and a microphone which establishes real-time communications. Each individual learner is free to roam throughout the IE and have conversations with other learners and also with NPCs. Typically, collaborative learning will occur through conversation about a particular topic, e.g. a group of five students may observe and discuss an experiment in gravity; they negotiate a path through concept clusters, and so come to a shared understanding. This approach to collaboration requires a theory of conversation, which may inform how ‘the spoken word’ may be used within an IE between groups of learners, perhaps with an instructor, or with programmed NPCs. One central use of the spoken work is the provision of a narrative by an NPC who is programmed to guide the learner(s) through the concept clusters. This is the subject of the following subsections.

The Theory of Discourse

Verbal communication is an important aspect of collaboration. This was identified in the mapping in Table 1. Two approaches to crafting conversations are discourse and dialogue. Candlin gives a definition of ‘discourse’ as the use of socially-contextualized language (Candlin, 1997). Discourse is constructive and dynamic which has the effect of structuring learners’ knowledge. Discourse allows the learners not only to talk and write about situations, but also to act within and upon those situations. This idea is familiar from Austin’s speech act theory where communication may change the social situation (Austin 2006).

Discourse is a linguistic, social and cognitive process; the interaction between speaker, listeners, utterance and context generates meaning (Thomas, 1995).

The defining characteristic of discourse is that it is has a goal which may be set by the teacher. Discourse is structured to move towards this state. NPCs can be programmed to guide the learners’ conversations, through posing questions, making suggestions and asserting directives. We have programmed NPCs to do all of this; they make use of recorded speech imported into the NPC code as ‘wav’ files. A first NPC has been programmed to support a dialogue with another NPC allowing conversations of constructor-defined length. A second NPC has been programmed to support conversations between groups of NPCs, again under the control of the IE developer.

Other theoreticians such as Grice suggest a communication model directed specifically at collaboration (Grice 2006). He identified several maxims that should be followed by participants in a true collaborative discourse; to be ‘informative’, ‘truthful’, ‘relevant’ and ‘clear’. We have used these maxims in our IEs. The material should be ‘informative’ in that it contains breadth and depth of information suited to the learning context, it should be ‘truthful’ in that it is correct and does not mislead the learner. It should be ‘relevant’ fo-
cussing on the learning issues without distraction, and should be ‘clear’ in presenting information within a minimalist frame while maximizing information throughput. This suggests that the material should be strongly contextualized, e.g. learning about gravity in physics should be related to concrete experiences such as jumping off walls, the motion of tennis balls, as well as to more abstract concepts such as space-craft re-entry. Sperber and Wilson (1995), in their cognitive approach to communication, suggest that the relevance of information presented is increased by the degree of contextualization.

Another theory which may inform cooperative discourse is conversational analysis, which aims to understand conversations where each participant is given a ‘turn to talk’ (Hutchby and Wooffit, 1998). This structures the discourse (preventing multiple overlaying talk), and also allows an efficient post-event analysis of the discourse. We have implemented this structure within several IEs. This relies on an ‘IE manager’ which coordinates the interaction between the learners, allowing only one learner to have the focus of interaction input at any time. Conversational ‘turn-taking’ has been studied by Sacks, Schegloff & Jefferson, who suggest that discourse may be enhanced through a parallel process of directing gaze between the participants (Sacks et al., 1974). We have programmed learner avatars which can sense the locus of their gaze and respond appropriately, e.g. a piece of text or observing an experiment. This affordance is used in conjunction with the ‘IE manager’ where the learners indicate objects using their ‘eye’ crosshair rendered on the HUD, request the conversation channel and talk about that object. As well as making turn-taking more natural, these avatars have other uses, e.g., we can record and analyze how a learner reads textual information, (e.g. sequentially or scanned) or learners can pick up selected objects. In one IE, designed for Primary School literacy education, learners walk through rooms choosing words using the crosshair ‘eye’ and then drop these words onto a ‘notice board’ to interactively construct sentences. The crosshair ‘eye’ provides a general and powerful interaction mechanism.

The above theories are microscopic, working at the level of individual sentences. A macroscopic theory is also required to structure entire conversations. Narrative theory can provide a suitable base. Narratives are a structured representation of desired events in temporal order; they provide a ‘time-line’ for the discourse, moving it from initial objectives to concluding goals.

A classic study of narrative has been made by Labov (1972) who defined several features which may be used to generate structured narratives. These are summarized by Ochs (1988), and here are related to a study of objects falling under gravity: (i) abstract, a summary of what is to be said. For example, we may construct the flowing narrative elements between two NPCs aimed to introduce collaborative experimenters to decide how to investigate the topic. E.g., “Let’s discuss what happens when we throw an object”, (ii) the orientation, “This is an example of motion of an object in gravity”, (iii) complication, “The theory states that …. and predicts that ….” (iv) evaluation, “So we need to choose between the following experiments…” (v) resolution, “It seems a good idea to try this experiment first…” (vi) coda. “Now, you the experimenter may wish to follow our advice”.

We have programmed several actors to support the various classes of conversation; (i) narrative, (ii) discourse and (iii) dialogue. These are illustrated in schematically in Figure 4 which depicts the ‘space’ of conversation for the three classes.

This illustrates that narrative, discourse and dialogue provide a progressive increase in the information transfer in conversation. Discourse within an IE comprising NPCs, learners (LE) and the teacher (TE) may be classified as follows: LE-LE, LE-TE, NPC-NPC, NPC-LE. A further approach we have investigated to analyze LE-LE collaboration was the ‘teamwork process model’ suggested by Salas et al., (1992). This work identi-
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Figure 4.

(a) (b) (c)

(0x)

flies six skills necessary to support collaborative learning: (i) adaptability, (ii) coordination, (iii) decision making, (iv) interpersonal, (v) communication, (vi) leadership. These dimensions provide a means to analyze transcripts of LE-LE discourse. Within an IE we have used a selection of pre-defined messages constructed according to the above classification. During a collaborative activity with a group of five students, measures of collaboration were distilled from the number of each message-type observed. The largest number of observed messages were ‘interpersonal’, involving somewhat spurious chat unrelated to the learning materials. We accept this as beneficial, leading to a cohesion of the social group. Leadership messages appeared as the second most prominent communication; there was clearly a period of negotiation where one leader emerged. The distribution of messages changed with time; when the collaborative group had converged to a stable dynamic, ‘communication’ messages predominated, where learners (together with the ‘leader’) had gelled into a collaborative group. A similar study has been made by Chung et al. (1999).

While discourse theory provides generative and analytical tools to reflect on conversations, it is limited by the existence of a goal state. A similar goal state is implied in Vygotsky’s socio-cultural theory. The Russian Bakhtin, through his ‘dialogic’ theory, opens up a larger space to situate conversational analysis and construction, and so to escape the confines of this ‘goal state’.

The Theory of Dialogic

Bakhtin’s theory of the dialogic as mediating thought and learning, rests upon the need to take on board the perspective of all others involved in the learning process, rather than focus on goals. Dialogic theorises the process of shared inquiry through dialogue. Dialogic is essentially an epistemology. Meaning is revealed through dialogue, (Bakhtin, 1986). This is emphasised by Rommetveit (1992) and Linell (1998) who highlight three aspects of the dialogic: (i) Communicative acts are mutually dependent and conspire to connect past and future acts, (ii) These acts are also in dialogue with cultural and social contexts, (ii) Meaning itself is not to be discovered, but to be created within the dialogic. There is no reference to objects but rather an assertion of human perceptions of objects.

The principal characteristics of dialogic theory is that there is no final goal as with discourse theory, that dialogue exists per se. Dialogue generates more dialogue and so recursively increases the space of dialogue. Within an educational setting,
The expansion of space is a direct consequence of the learners’ learning and induces more learning. Within the example of the study of objects falling under gravity, learners’ dialogue may start around the concept of gravity. Since gravity concerns fields and force, the dialogue may branch into discussion of either fields or force.

**Technological Implementations of the Dialogic**

The use of technology in education should follow from a reflection on pedagogical principles. But this has not always been the case. Various approaches can be identified. The simplest is found perhaps within intelligent tutoring systems. Following Wegerif and Dawes (2004), insertion of programmed prompts such as “what if?”, “why do you think that?” can stimulate reflection and open up the dialogic space. Such prompts may be elicited by NPCs or via programmed player avatars as suggested by Ligorio and Pugilese (2004). A second level of complexity may be found in the use of multi-modal assets where dialogue may emerge through engagement with both textual and non-textual representations of meaning. This serves a dual purpose; first, it is more inclusive, second it allows learners to reflect upon the communicative power of different modalities. Dialogue may be also inserted into narrative or discourse, providing opportunities for expansion of communication, (see Section 5 on topology). This difference is expected to emerge through learner-learner dialogue, but can also be instigated through NPCs who are programmed to introduce concepts against an alternative and so open up an expanding space of conversation.

Wegerif has proposed some design principles for dialogic IEs: (i) Address the issue of what it means to collaborate and promote the use of ‘reflective dialogue’. (ii) Do not use ‘taking turns’ in dialogue, rather encourage prompting learners to talk together. (iii) Selection of alternatives rather than long typed input. (iv) There should be a narrative which surrounds the learning issues. (v) Problems should be constructed to require distributed and not individual thinking. (vi) Dialogue should be scaffolded by images or symbols which can be pointed to or manipulated. (vii) No time constraints should be imposed, rather activities should be interspersed with moments for reflection. (Wegerif 2007). All these principles can be effected using IE technology such as images, sound and various modalities of interaction.

Walton has approached the dialogic from the point of view of argumentation. His approach is to set up a system of rules, and judge the ensuing dialogue against these rules. In his work *The New Dialectic* he asserts six fundamental types of dialogue: (i) persuasion, to resolve an issue, (ii) inquiry, to find and verify evidence, (iii) negotiation, to achieve a compromise, (iv) seeking information, to find or contribute information, (v) deliberation, to coordinate actions with intended outcomes, (vi) ‘eristic’, to verbally assault the perceived opponent (Walton 2000). Such rules can be easily programmed into the behaviour of NPCs which will in fact guide the learner-learner dialogue.

Rommteveit and Per Linell consider the epistemology of dialogic. Meaning is created within a dialogue, through the juxtaposition of the various learners’ perspectives, where one true meaning emerges from a field of possible alternative interpretations. This, of course, is pure existentialism. In our context it emphasises that learners should not be seen as processors of information, but through engagement with metacognitive processes, (thinking about thinking) learners come to develop new skills to be used in new learning situations. This will result from learner-learner discourse or dialogue.

**Other Aspects of Collaborative Conversation**

We have emphasized the distinction between conversational discourse and dialogue yet there
are other conversations which do not fit into this mold. Conversation through writing has been highlighted by Graves (1983), where learners collaborate to draft, review and finalize written compositions. The ‘Reciprocal Teaching’ metaphor developed by Palincsar and Brown requires students to discuss and question each others’ textual material. Discussion of text leads directly to cognitive growth. Deep conceptual understanding may result through the learner’s activity of explaining one’s conception to one’s peers. This involves an individual commitment to personal understanding e.g., Brown and Palincsar (1989), whereby the inadequacies of the individual’s perspective becomes informative. Dillenbourg (1999) speaks of a “space for misunderstanding” where learning may result from resolution of misunderstanding. Working within such a metaphorical space may be more efficient than a conversation free of ambiguity.

From a cognitive point of view, the process of explaining a problem to other learners deepens conceptual understanding since each individual learner is forced to commit to some ideas, explain their beliefs and reorganize their knowledge in the context of the collaborating group (Brown and Palincsar, 1989). Research has shown that the act of externalization of individual thought processes within a social context, so that the individual’s processes become visible, where they can be imitated and examined, engages metacognitive processing. Monitoring of the individual’s thought processes can lead to advancement of these processes.

Such monitoring can be explored in our IEs through a process of ‘logging’ critical student activity and their engagement, which provides a useful tool for examination of cognitive thinking and learning.

**Dynamics of Collaborative Learning: Coupled Kolb Cycles**

To capture the dynamics of collaborative learning we return to Kolb’s learning cycle, as providing the simplest dynamical system description of learning situated in a social context. Individuals’ learning cycles become effectively interconnected, but the question arises as to how these may interconnect. Taking our proposed metaphorical structure as an interconnected network of concept clusters each containing a Kolb cycle, a naïve approach would be to assume that a group of five or so learners would march together in lockstep through this cycle, residing in each stage at the same time. However, this was not Kolb’s intention. The idea behind the dual dialectic of (i) concrete experience – abstract conceptualisation, (ii) active experimentation – reflective observation was to identify individual learning styles where the individual learner would find a position along the dual poles and engage with these styles as individuals, (in our metaphor, this implies activities within one or more Kolb rooms). This suggests that while all collaborative learners may move through a particular Kolb cycle, they may do so with different phases, i.e., different learners may tardy in different Kolb rooms. This may lead to group fragmentation and re-crystallisation.

**How to Design Collaborative IEs**

Collaborative systems are based on constructivist principles of learning. From the design perspective, Duffy and Cunningham’s (1996) design framework is a good starting point. They propose seven design principles. (i) Construction of knowledge. Learning activities should enable students to direct their own learning, to be autonomous learners in order to construct their own knowledge. (ii) Multiple perspectives. IEs should contain learning experiences which place the individual learner beyond his own point of view. This can be done through conversations. (iii) The context. Learning materials and activities should be authentic; learners’ thinking becomes aligned with actual practice (Honebein 1996). (iv) Mediated action. This refers to the tension between the IE used as a socio-cultural mediation tool, and as a means of
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carrying out concrete actions (Wertsch, 1994). (v) Social dialogue. Learning is a social and discursive process which uses ‘talk’. (vi) Socio-cultural learning. Learners do not learn as individuals but through initiation into the practices of a learning community (vii) Knowing how to know. This is the most important of Duffy and Cunningham’s principles. It implies an increased awareness of the learner’s psychological state and is realized through situations where the inadequacies of the learner’s belief structures are revealed.

We relate our IE affordances to the above design framework: (i) Our IEs consist of a network of rooms and passages containing various resources to engage learners of various levels of ability and styles of learning. (ii) Like cubist art, our IEs contain experiential assets which provide multiple perspectives allowing various forms of engagement with the learning material. (iii) Our IEs are ‘authentic’ since they mirror processes and situations encountered within the real world, while asserting a simplification to remove extraneous factors or ‘noise’. (iv) Our IEs relate the execution of individual physics experiments with the process of scientific peer-review. This is a characteristic of collaborative learning where the results of experiments are reviewed by the collaborating group, and decisions made on how to proceed through the IE. (v) Social dialogue is effected through the IE affordance of real-time conversation. (vi) This is a meta-level of social dialogue where learners converse in groups and with the instructor or programmed NPCs. (vii) This transcends all technological implementation and develops in each learner as a consequence of social dialogue, where the socially developed understanding is reflected back into the individual learner.

Dillenbourg emphasizes the idea that collaboration triggers various ‘learning mechanisms’. Some mechanisms are already present in individual learning processes, such as induction and deduction, others such as disagreement, explanation and mutual regulation are specific to collaboration. He suggests that the design of IEs should increase the chance that these interactions will occur. Our interpretation of Dillenbourg leads to the following design rules, posed as questions: (i) What is the structure of the collaborative group? Should the learners be homogeneous or heterogeneous in ability? What is a good group size? Research into these issues has revealed that the situation is complex; there are various interdependent factors. No clear guiding principle has emerged (Dillenbourg et al. 1995). (ii) What are the ‘roles’ of the individual learner within the group? Should these be assigned? Should an IE be crafted to assure ‘conflicting’ interactions which stimulate learning? Should learners be assigned roles even though these do not express their individual beliefs? (iii) How to scaffold by establishing rules of interaction, e.g., learners are required to communicate using pre-defined messages (Baker and Lund 1996). (iv) How to monitor and regulate interactions? This could be the ‘facilitator’ role of the teacher. Approaches to designing collaborative IEs have been frustrated by the lack of structure within the domain (Spiro et al. 1988). Slavin (1997) proposed four perspectives which may inform instructional design of collaborative IEs; motivational, social cohesion, developmental and cognitive elaboration. Social-constructivist theory informs us that meaning is constructed, in student workshops, through activities and talk. But this cannot occur unless we provide appropriate learning opportunities and also be sensitive to learning orientations, dispositions and motivations. Another aspect which is useful to inform construction of IEs is the closed-open group dichotomy. Within the closed group scenario, learners decide their learning objectives in advance, and so these objectives become static. On the other hand open-ended collaboration is grounded in a conversational dialogue where issues emerge from collaborative discussion. This reflects the discourse – dialogic dichotomy.
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METAPHOR

We have asserted the use of metaphor as well as direct correspondence through a common ontology, as providing a mapping between the affordances of computer game technology and the requirements of a contemporary pedagogy. In this section we review our use of metaphor and develop this in various dimensions. We have already encountered the use of a spatial metaphor in relating knowledge structures, to the topology of an IE. The power of the metaphor, as a design and analysis tool, lies in its establishment of a correspondence (loose or strong) between various domains of our human experiences in the physical world, and the virtual worlds we wish to create. The use of metaphor validates these IEs in the sense that it attributes meaning to the IE, through a link with the physical world and learners situated within that world. The power of the spatial metaphor has previously been identified by Lakoff (1987).

Metaphors of Space

In representing the physical world, an IE should not simply reproduce that world, but aim to allow the learner to produce a personal and meaningful interpretation of that world. This suggests condensing the complexity of real-world situations into a smaller space of interactions. As mentioned above in the case of physics experimentation, the IE provides the richness of real-world experimentation but in a confined context where factors extraneous to the object of study are eliminated. In other words ‘noise’ is eliminated.

Ben-Zvi and Sfard (2007) provide an interesting and challenging metaphor of a learning space. Ariadene, when attempting to release her beloved Daedalus from the Minotaur labyrinth, provided a thread which was intended to be followed without question. This corresponds to an instructional metaphor. This is a directed trajectory through space, aimed at a goal defined by the teacher of the curriculum. Sfard highlights the restrictions of such an approach which is focused on one situation and one individual. Learning cannot be individually focused, it must be able to guide everyone through the labyrinth of knowledge and understanding.

We have produced several IEs where the instructor guides the learners through a web of concepts and activities; the instructor has been realized as both a human participant and as a programmed NPC providing a focusing narrative. Such IEs have been popular with learners since they provide a clear learning trajectory. It seems that learners feel the need for a clear pathway rather than a ‘garden of forking paths’.

The metaphor of a ‘shared learning space’ where knowledge and expertise may be pooled is important. Such a space takes on the role of a frame of reference for collaboration, and leads to development of IEs where collaboration may occur. Such a space should support principles of working together, trust, integrity and allow the possibility of ‘break-through’ (Marshall, 1995).

Several of our physics IEs contain a combination of resources such as experiments, text-based materials and ‘experts’ in the form of programmed NPCs or even an expert instructor. Unlike the Kolb clusters, these spaces are not structured but are amorphous, intended to allow learners to discover how to collaborate outside the metaphorical classroom presented by the Kolb clusters.

White and Seigel (1984) make an interesting use of the metaphor of time and space in understanding the cognitive development of the learner. They situate the development of thought, from concrete to abstract, as a journey through space and time. As children grow up, their spatial experience increases, (they walk to school, they explore a city). At each stage of development, this increasing space provides cues informing their behaviour. Learning in space is natural. Spatial relationships within the physical world inform relationships between iconic symbols of
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concepts. “A child who draws a map or makes a model transforms the world into an imitative symbolic code” (White and Seigel, 1984). Their learning becomes situated within physical space, and is transformed to the cognitive structures of their understanding.

The suggestion here is of a particular journey through physical space, the streets and buildings of a town. Making this journey involves choosing a subset of all possible routes, perhaps informed by personal choice. The associated metaphor is one of simplification, or reduction in the complexity of the situation, a single path is chosen from many. This may be used as a design principle for IEs, where learning rooms and pathways represent a simplification of real world phenomena, so that the learner is presented with a sufficient (but rich) learning experience.

We conclude that an IE learning space may be characterized by (i) a simplification of the complexities of real physical space where learning goals may be efficiently realized without distraction, (ii) a space where direction provided by the teacher may be emphasized but not prescribed, (iii) a context for collaboration, (iv) a path through space and time where the development of the learner may be realized and documented.

**Embodiment**

Various concerns relating to contemporary existence within cyberspaces (such as the Internet and ‘Second Life’) have been raised (Dreyfus, 2004). Dreyfus asserts that without a bodily engagement (‘embodiment’) with phenomena, we lose the ability to appreciate the meaning and relevance of these phenomena; there is no grounding to inform us of the validity of the information we retrieve. Dreyfus asserts that through a bodily engagement with phenomena we are able to attribute meaning to our experiences. This claim is also asserted by constructivist theoreticians; the absence of a real-world context prevents the acquisition of meaning. This is supported by Dewey’s theory that learning should be grounded in experience, Levin’s theory that learning should be active and Piaget’s theory that the interaction of person and environment affects intelligence. Embodied learning implies that IEs reflect the ‘natural complexity’ of the physical world where the learner distills understanding from this complexity (Spiro et al., 1988).

Embodiment is not equivalent to ‘immersion’ in a virtual world. It implies a deeper relationship between the learner and the IE, where the dynamics of the IE influence the learner, and where the actions of the learner change the substrate of the IE. The reciprocity of this relationship, in a generative sense, informs both the evolution of the learner and of the IE, an ecological process. Generation of information and appreciation of meaning are not defined *a priori*, but emerge through a human-substrate interaction.

A novel metaphor which relates the learner to the real world is ‘cognitive apprenticeship’ (Collins, 1991). Here, learners encounter knowledge in situations that foster invention and creativity. This metaphor employs different pedagogical tools than traditional instruction, such as modeling world-based processes, and expert activities. Through this modeling, learners become aware of how experts solve problems, how they generate solutions, and how they create new artifacts, such as knowledge. The learning processes here include imitation and reification. The cognitive apprenticeship metaphor is characterized by articulation, (making knowledge explicit) and exploration, (how to form and test hypotheses). This is reminiscent of the Bauhaus movement which combined high-theory and practice aimed at commercialization, a metaphor which is surely of importance to inform HE course development? Our discussion of embodiment (above), suggests that learning should be situated in the real physical world, society and culture. It has been suggested that the most effective learning is case-based,
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i.e., involves a ‘world-take’. Grounding learning within the skills-based world while creating an open space of academic reflection requires a sensitive mix of practical and academic learning. The corresponding metaphor is the 1920’s Bauhaus movement in Germany which combined theoretical study with ‘apprenticeship’.

Systems Thinking

Systems theory provides useful metaphors for informing the development of IEs. There are two poles to systems thinking. At one end is the theory of ‘Hard Systems’, (based upon a mathematical description of an underlying ontology), to ‘Soft Systems’, (based upon human perceptions of that ontology). There is a clear correlation here with Sfard’s approach. In her acquisitional versus participatory metaphors, she makes exactly this distinction between hard and soft systems approaches.

In terms of learning and teaching, systems theory may be used as a metaphor to situate knowledge acquisition, and constructivist approaches to this goal. Systems theory considers ‘open’ and ‘closed’ systems, where the latter are defined by a consistent set of principles, which cannot respond to influences from outside the system. Open systems are constructed with dynamics able to respond to ‘external’ events such as human input. Traditional computer learning environments are closed, supported by goal-driven programs unable to cope with individual learning styles. The characteristics of open systems include (i) response to learners’ needs, (ii) interactions initiated by the learners, (iii) providing a space which is intellectually and conceptually challenging. Such open IEs should reflect the complexities of the real world and not hide them. They should engage the learner with these complexities, through real-world case-based activities, and through collaboration to reflect on the nature of this context.

The Internet and Hyperlinks

Hypertext conforms to the principles of constructivist learning since the use of hypertext to acquire knowledge engages the learner in constructivist processes (Jonassen & Wang 1993). Learners browse with existing knowledge structures in mind, providing an extensible context and eliciting learning. We propose that the topology of the Web, and the processes of navigation may act as a metaphor for the construction of IEs. Rooms within an IE are as to web-pages, passageways and teleporters are as to hyperlinks. There is a metaphorical equivalence of topology which results from the shared nonlinearity of hypertext and the IE. We suggest that educational IEs may be constructed according to the hypertext metaphor, where rooms (i.e. pages) containing associated information may be linked to others.

Emergent Properties

Emergence refers to experiences within an IE which have not been explicitly constructed. If the IE contains a large enough number of deterministic elements, unexpected behaviour may emerge, e.g., interactions between NPCs.

Sfard sees collaborative learning as following an emergent participation metaphor. Learning is not prescribed, rather it is about becoming a participant; the learner’s knowledge emerges through practice, activity and discourse (Sfard, 1998). In this metaphor, meaning is never given, but is created. It emerges from dialogue between different perspectives; it is carved out from a space of a field of multiple interpretations (Bakhtin, 1986). Within the dynamic of the collaborative group, the metaphor of emergence is also realized in the context of structuring the group activity and the role of the participants within that group. Research has indicated some guiding principles, e.g., concerning the structure and induction of the group: Collaborative groups function best when an expert is asserted. Such structures may encourage
emergence, for example, the emergence of one learner playing the role of the teacher.

Students today are encouraged to choose their own learning trajectories rather than converge to a teacher-defined goal. Sfard describes this as a shift from the ‘acquisitional’ to the ‘participatory’ metaphor. Students no longer have a conversation with the world, but rather with others’ perceptions of the world, (Sfard, 2008). Here language is fundamental, since learning becomes a process of modifying and extending one’s capacity for discourse. Sfard goes on to posit that there are two levels of learning; the object-level and the meta-level, both of which are necessary for a learner to progress from novice to expert. At the object level, learners will discuss material within a provided linguistic field, e.g., in the study of gravity, learners will encounter experiments, textual descriptions and explanations. Within this linguistic field, they will be able to progress in learning and come to understand associated concepts. Since a field exists a priori, there is no need for a teacher to be present. However, the situation jumps dramatically when further material is introduced which requires a different linguistic field, e.g., the application of gravity, which normally causes downward acceleration, to hot-air balloons which rise upwards. This new linguistic field lies outside the learners’ experience, and therefore cannot be learned autonomously and so must be taught. This is a meta-level of learning where a new vocabulary must be introduced (by the teacher) in order to establish an expanded space of discourse. We have programmed NPCs which can facilitate jumping between linguistic fields. Typically, they introduce new vocabulary at the appropriate place in the IE topology such as at the point of introducing a higher-order concept.

**TOPOLOGIES**

We have so far used knowledge structures, Kolb cycles and adaptive learning principles to inform the topological structure of an IE. In this section we consider topology in its own right; the design of IEs may be usefully informed by these, and other, topologies. An IE topology is defined as a set of ‘nodes’ connected by ‘arcs’. A node can be a single room, or a combination of nodes and arcs. An arc can be a passageway or a teleporter. These may be uni- or bidirectional; a passageway can be made unidirectional by use of a triggered door. An arc may be considered as ‘open’ or ‘closed’, its state being determined by some event, e.g., from a trigger pressed by the learner or induced from the learner’s state. We have identified several classes of composite nodes useful in designing IEs. A ‘grammar’ of topology may be considered where each node may contain another composite node, perhaps recursively. Some possible composite nodes are illustrated in Figure 5.

In (a) we have a simple linear sequence of nodes which may be used as a backbone for more complex topologies. Composite (b) shows the basic branch where particular arcs could be opened or closed providing the basis of choice. In (c) there is a menu of choices which return to the menu. This is useful at the highest level of the topology hierarchy. A hyperlinked structure is shown in (d) where all arcs are shown bidirectional and open, but in (e) the choice of links within a single hyperlinked structure is determined by the user. Here we have in mind that the learner actively reconfigures the IE according to personal choice. For example they may be asked to rate particular nodes, or to indicate which they find useful or not. In this way the learner constructs a personalized learning space. In (f) there is branching with dead ends; only certain choices lead to deeper investigation. The most complex topology is (g) where the user is able to interactively build the IE topology. This is simple to effect within an IE ‘control room’ where the learner is presented with a complete set of nodes with a description of learning activities contained within each node, where they select the desired nodes. A topology is built up ‘on the fly’, and the learner enters this personalized learning space.
Having designed a base topology of nodes, a further design principle can then be invoked; this uses the metaphor of ‘overlays’. An ‘overlay’ comprises a subset of the base topology nodes and arcs which provides additional functionality. One example is the location of NPCs providing narrative, guiding the learner through the base topology. This includes introduction of new vocabulary to ‘jump’ into a larger linguistic field as discussed in Section 4.5. A further example could be the location of specific educational events, such as nodes of assessment or IE modification. Viewing the base technology in terms of overlays allows an additional design principle to be deployed.

**CONCLUSION**

In this chapter we have argued the need for a theoretical basis for the development of serious games for education and training derived from pedagogical principles and have given some examples of how technology and pedagogy may be related. We have grounded the processes of non-collaborative and collaborative learning in contemporary learning theories. The metaphor of ‘space and time’ has been introduced as both an analytic and generative methodology. The virtual space of the IE, mirroring real physical space may be used as a metaphor for some third abstract space, such as knowledge structures expressed as concept maps. The virtual time within the IE, mirroring physical time, may be used as a metaphor for learning dynamics, such as expressed in experiential learning theory. Taken together, the ‘space-time’ metaphor provides a basis for understanding collaborative learning, where discourse and dialogue running through time are embedded in space and are able to capture the true socio-cultural aspects of learning. A distinction between three types of conversation, narrative, discourse and dialogue has been emphasised, since conversation is an important substrate for collaboration. We suggest that the concepts of ‘metaphor’ and ‘topology’, combined with pedagogical theory may usefully inform the creation of educational immersive environments.

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