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Learning spaces, tasks and metrics for effective communication in Second Life within the context of programming LEGO NXT Mindstorms™ robots: towards a framework for design and implementation

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Abstract

Science education is concerned with the meaningful pursuit of comprehension, knowledge and understanding of scientific concepts and processes. In Vygotskian social constructivist learning, personal interpretation, decision-making and community cooperation foster long-term understanding and transference of learned concepts. In short, the construction of knowledge requires learners to be actively involved in the process of learning. This paper presents a discussion of the method used to assess and define effective measurements. We use these measurements to evaluate strategies for communicating science by using LEGO robots and a Mindstorms™ RCX controller that are collaboratively constructed and programmed by students in a virtual technology (Second Life). This occurs while the students are physically situated in different locations.

Keywords: learning spaces; social constructivism; pedagogy

Learning spaces, tasks and metrics for effective communication in Second Life within the context of programming LEGO NXT Mindstorms™ robots: towards a framework for design and implementation.

Context

Our findings originate from an international collaborative project tasked to develop metrics for establishing the success of learning within immersive environments. Within this project we propose approaches to designing effective educational tasks composed of different learning objectives and include a framework for them; we also present an effective learning and teaching pedagogy. We describe the development of these metrics and our method and also discuss how they were applied to a specific project, including an evaluation of strengths and weaknesses.

Science education is concerned with the meaningful pursuit of comprehension, knowledge and understanding of scientific concepts and processes. This paper presents a discussion of the method that has been applied to assessing and defining effective measurements that evaluate strategies for communicating science. We use LEGO robots and a Mindstorms™ RCX controller collaboratively constructed and programmed by students using a virtual technology (Second Life) while physically situated in different locations. This paper reports a set of experimental protocols that were designed to elicit the metrics which may be applied to bring about successful learning within such an environment.

Ours is an international collaborative project between three universities: one in the UK and two in Japan. We were to develop metrics for establishing the success of learning tasks within immersive environments as well as to propose approaches for designing effective educational tasks for different learning objectives. Then the team was to design a framework for these objectives and tasks and for effective learning and teaching pedagogy.

The research team adopted a mixed-methods approach to combine data from in-world transcripts, reflective diaries, individual interviews with subjects, psychometrics, robotic programming data, and transcriptions and coding from video capture of interaction sessions between participants. Participants were required to discuss, design and solve real-world and in-world programming challenges.

Beyond traditional practice

Research in the informed use of technology for educational purposes highlights the need to go beyond the replication of traditional, didactic practices to an appropriation of digital communication (Warschauer, 1999) facilitated by a constructivist pedagogy (Jonassen & Land, 2000) to support purposeful tasks (Martin & Vallance, 2008). The convergence of instructivism, constructionism, and social and collaborative learning towards a cohesive ‘Conversational Framework’ (Laurillard, 2002) provides opportunities for learners to take, “a more active role in learning and for tutors to support learning activities in multimodal ways” (deFreitas & Griffiths, 2008, p.17). Technologically enhanced learning makes possible a “shift from merely exposing the learners to the material, to transforming the learning environment” (Dror, 2007, p.5). This paper reports a set of experimental protocols which were designed to elicit the metrics that may be applied to bring about successful learning within such an environment as part of an ongoing project¹.

¹ See <http://web.me.com/mvallance/PM12/PM12/PM12.html> for project background

Virtual worlds are ideally positioned to enable educational transformation—they permit the creation of new learning environments with unique tools and communication opportunities, all of which can support inter-disciplinary and intra-disciplinary collaboration and build bridges between education and experience (Jarmon et al, 2009; Field, Vallance & Yamamoto, 2008). The first phase of adoption often attempts to create engaging experiences in these new learning environments by replicating familiar real world buildings and institutions (Jennings & Collins, 2008) together with their associated approaches to the learning experience. This transposition of existing practice to these virtual world environments may not be appropriate and does not effectively utilize their unique design and communication opportunities in meaningful ways. One informed educator in the Second Life (SL) virtual world summarizes her experiences of this approach:

After attending numerous educational meetings in SL, my tolerance for mapping real world activities directly into the virtual world fell into sad decline. Sitting in a closed classroom space while being silent, waiting to raise my hand to speak is in direct contrast to how I teach and interact in a virtual world. Many favor these practices, and perhaps there are more examples of traditional methods than is apparent at first glance. My penchant for employing less traditional learning spaces does not mean that I advocate classroom chaos, but that I like to leverage virtual world capabilities beyond what we can do at our brick-and-mortar campus and in our online course management systems (Calongne 2007, p.111).

Innovative articulation of virtual world collaboration requires a uniqueness of contribution by participants (personally or anonymously), synchronously and/or asynchronously (whichever is most comfortable for the user) with a democratization of the process that can lead to a sum product greater than individual contributions (Vallance & Wiz, 2008). This represents a move from the commonly seen replication of existing practice towards the exploitation of the unique pedagogical affordances offered by emerging technologies; a move from first to second order change (Cuban, 1992). To implement this change, tasks are required that promote learner activities which would be difficult, if not impossible, in the real world. As deFreitas (2008) asserts, “In order to achieve this next step two related aspects are required: the first is developing better metrics for evaluating virtual world learning experiences, and the second is developing better techniques for creating virtual learning experiences (e.g. frameworks, approaches and models)” (p.11).

The challenge posed by deFreitas is for educational researchers to develop valid, reliable and transferable metrics for assessing the teaching and learning effectiveness of virtual worlds. Transformation of learning and of pedagogical practices can only be accomplished from evidence that supports and highlights the resulting benefits of such change.

Theoretical context

Teaching takes place within the context of educational philosophies based on theories of how people learn. Furthermore, epistemological considerations influence course design and pedagogy regarding the strategy teachers use to facilitate learning. While these theories and resulting teaching techniques vary, the idea of learning as acquisition and as participation has underpinned much educational thought (Rovai et al, 2009, p.2).

Bloom provides a taxonomy that has allowed educators to visualize teaching objectives and perceived learning and the associated notation, categorization and assessment of aims (Bloom, 1956; Anderson et al, 2001). Anderson et al (2001) posit that “(a)ll frameworks such as the taxonomy are abstractions of reality that simplify in order to facilitate perceptions of underlying orderliness” (p.259). From the development of its original format in 1956 to its revision in 2001, Bloom’s taxonomy (Figure 1) has been widely adopted and extensively cited as a useful way of framing what happens in a potential learning situation. It was adopted as the theoretical context for our study in line with a widespread academic consensus that “(i)n a field marked by wide pendulum swings, the likelihood of finding an idea, concept, or point of view that has remained constant in its acceptance and application is small indeed. Without doubt, the taxonomy is one of these rarities” (Anderson & Sosniak, 1994, p.viii).

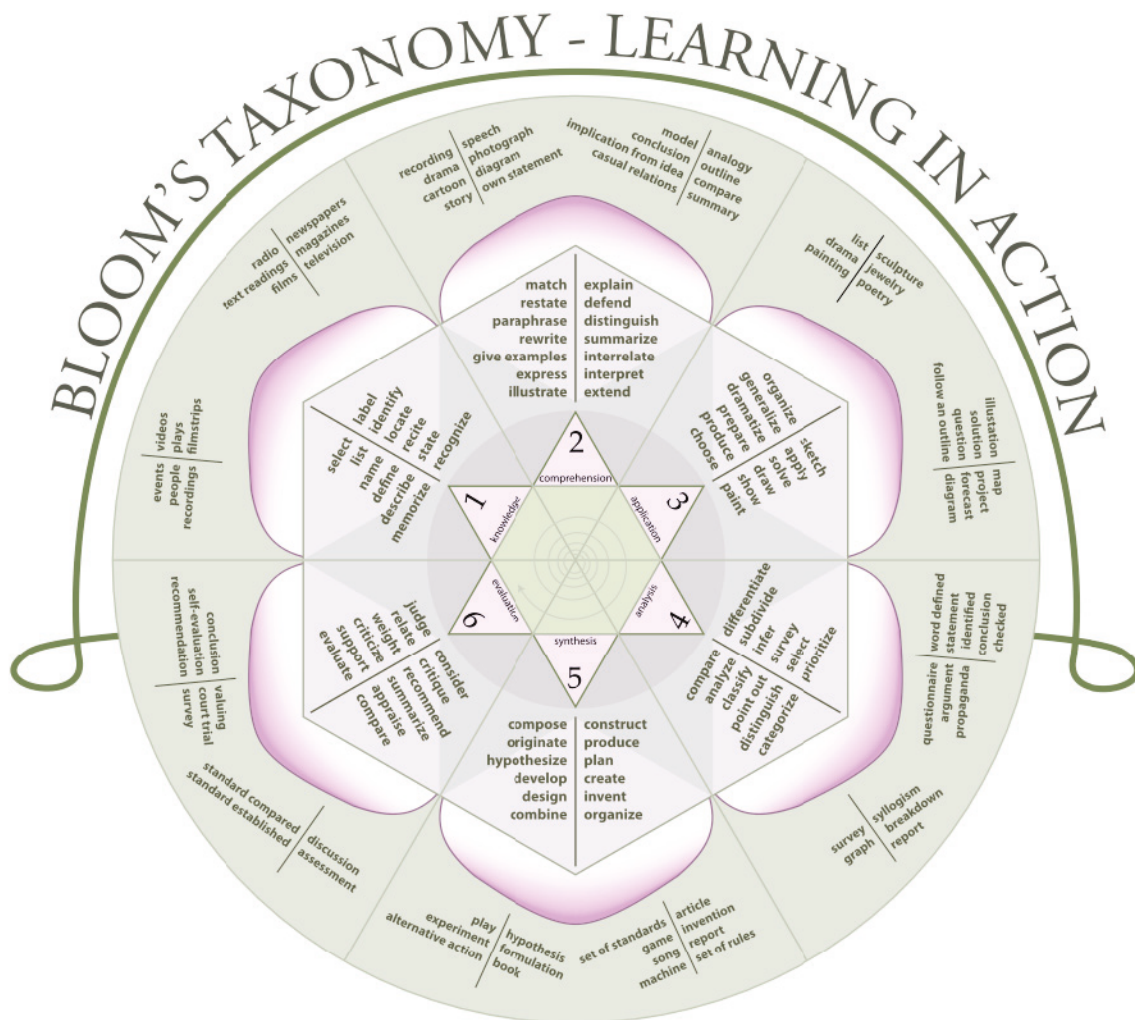


Figure 1. Bloom’s Rose. Aainsqatsi, 2008; after Manuel, 2000.

In Bloom’s taxonomy, a range of learning objectives are presented as cognitive functions (Anderson et al, 2001) that enable cognitive learning, that is, “... recall or recognition of knowledge and the development of intellectual abilities and skills” (Bloom, 1956, p.7). The six

categories associated with the cognitive domains identified in the revised taxonomy are: (1) remember—retrieve relevant information from long-term memory; (2) understand—construct meaning from instructional messages, including oral, written, and graphic communication; (3) apply—carry out or use a procedure in a given situation; (4) analyze—break material into constituent parts and determine how parts relate to one another and to an overall structure or purpose; (5) evaluate—make judgments based on criteria and standards; and (6) create—put elements together to form a coherent or functional whole, reorganize elements into a new pattern or structure (Anderson et al, 2001). The verb sub-sets associated with these cognitive processes are: (1) remember—recognize, recall; (2) understand—interpret, exemplify, classify, summarize, infer, compare, explain; (3) apply—execute, implement; (4) analyze—differentiate, organize, attribute; (5) evaluate—check, critique; and (6) create—generate, plan, produce. Supporting the cognitive processes are four general types of knowledge that include: (1) factual knowledge—knowledge of discrete, isolated, content elements; (2) conceptual knowledge—knowledge of more complex, organized forms such as classifications, categories, principles, generalizations, theories, models and structures; (3) procedural knowledge—knowledge of how to do something; and (4) metacognitive knowledge—knowledge about cognition in general, as well as awareness of and knowledge about one’s own cognition (ibid).

Knowledge	Cognitive Process					
	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual						
Conceptual						
Procedural						
Meta-cognitive						

Table 1. The taxonomy table; after Anderson et al, 2001.

A strength of Bloom’s taxonomy is that it provides a visualization of a relationship between both cognitive processes and knowledge (Table 1). It allows researchers and practitioners to sort out complexities and identify gaps where none may have been previously acknowledged. By adopting the revised Bloom’s taxonomy and the associated descriptive verbs, educational practitioners can use research outcomes to develop advice for creating assignments intended to have certain desired objectives. The clarity offered by the taxonomy has potential to make virtual worlds more accessible to educators and to allow exploration of the ways in which they differ from more traditional learning contexts. The activities of students during the process of virtual task implementation can be assessed in terms of their success in meeting the specified objectives and the alignment between ‘objective – activity – assessment’ should make virtual world tasks more integrated, transparent and coherent to both learner and educator.

Using constructivist pedagogy to support purposeful tasks

In Vygotskian social-constructivist learning, the learner’s interpretation, decision-making, and community cooperation fosters long-term understanding and transference of learned concepts. Learning is considered to be a “process whereby knowledge is created through the transformation of experience” (Kolb, 1984, p.41) and the construction of knowledge thus requires learners to be actively involved as participants in the process of learning. This requires an instructor’s pedagogical approach to be anchored in such a way that students meaningfully

‘experience’ their learning. Learning, then, is deemed to rely upon active learner engagement; virtual worlds provide an opportunity to explore a new space for the cognitive process. The student can do this by facilitating active learning through the transfer of control – as Dror (2007, p. 5) says: “providing control to the learners helps to achieve active and motivated learners, and when they are involved, participating, engaged, and interacting with the material, then learning is maximized.”

deFreitas and Neumann (2009) suggest that the appeal, immersivity, and immediacy of virtual worlds in education requires a re-consideration of how, what, when, and where we learn and offer their Explanatory Learning Model (ELM) based upon constructivist experiential learning as a way forward. The ELM extends Kolb’s (1984) model of experiential learning to provide a ‘cycle of learning’ (Mayes & deFreitas, 2007) consisting of:

- situative learning—where learners engage in communities of practice,
- cognitive learning—which builds upon experience, reflection, experimentation and abstraction, and
- associative learning—employing feedback and transfer.

deFreitas and Neumann (2009) also use Dewey’s concept of inquiry (pre-reflection, reflection, and post-reflection) to posit that learners’ virtual experiences, their use of multiple media, the transactions and activities between peers, and the facilitation of learner control between them lead to ‘transactional learning’. The ELM “aims to support deeper reflection upon the practices of learning and teaching” which arguably leads to “wider opportunities for experiential learning” (ibid p.346).

Two recent studies suggest that this concept has merit. Hobbs, Brown, and Gordon (2006) studied students’ interactions within Second Life while completing a series of complex, open-ended tasks and found that, “with careful planning the intrinsic properties of the virtual world can inform transferable skills and provide a rich case study for learning” (p. 9). These conclusions are supported by Jarmon, Traphagan, Mayrath and Trivedi’s (2009) study, using a mixed methods approach demonstrating the effectiveness of Second Life in a project-based experiential learning approach where students learn by doing and then apply ‘virtually’ learned concepts to the real world.

In constructivist learning students are engaged in active cognitive processing (as opposed to simply recalling or memorizing information); they are paying attention to relevant incoming information but are also organizing this into a coherent representation and integrating it with existing knowledge (Mayer, 1999). A principal characteristic of constructivist learning is collaboration among learners but while virtual worlds can facilitate interactions between instructors and students, not all individuals or groups automatically possess the knowledge, attitudes and sensibilities to work together effectively online (Vallance, Towndrow & Wiz, 2010). Some learners may require induction and practice before they are able to leverage benefits from collaborative learning; initial exposure to immersive collaborative environments may therefore not advantage all students equally. Towndrow and Kannan (2002) observed that individuals, regardless of specific task objectives, collaborate best when they have shared knowledge and interests. These preconditions are met in two ways: when online collaborators

build on prior face-to-face working relationships; and when inputs from collaborating partners are balanced in terms of vision and effort.

The aim of many learning situations is to enhance knowledge and understanding which, in Constructivist theory, are not external aspects to be captured but are uniquely internally constructed by individuals; each makes meaning of their own experiences. Constructivism does not prescribe planned strategies of instruction but advocates the creation of learning environments that provide opportunities to engage learners in meaning making. Collaboration thus occurs when learners effectively communicate their understanding, engage with the views of others and reflect upon their encounters (Miller & Miller, 1999), but does not assume all students are similarly equipped to do so.

Experimental design

When created, effective metrics for designing and evaluating effective learning in immersive virtual environments (IVEs) may draw upon a range of factors and different data types. We adopted a mixed-methods approach therefore, to provide access to rich qualitative and quantitative data enabling different possible relationships and hypotheses to be explored in a context that seemed more likely to offer opportunities to discover relevant factors.

The educational tasks provided for students within the virtual environment required a representative range of authentic activities found in real world scenarios, while being broadly typical of problem-solving activities used in engineering and science classrooms, all the while being sufficiently representative of those learning situations within other subject areas to permit generalization. The two characteristics selected were the intrinsic level of task difficulty and the availability of information relevant to the task. In both real world and classroom-based contexts some projects will be more challenging than others and in every case either more or less information relating to the task will be available. Relatively easy tasks can become more challenging if little information about their context or relevant variables is available while otherwise challenging tasks can become less so if, for example, significant information about important constraints and relationships is provided. Task difficulty and available information were therefore applied in our study as key design parameters.

We are interested in exploring the degree to which learning activities in virtual worlds are likely to provoke behaviors which can be located within Bloom's revised taxonomy. The current project was conceived to facilitate an exploration of this by studying the communicative exchanges between and within teams during problem solving activity. A closed and highly defined task seemed most likely to provide the necessary comparability and empirical data to determine the success of task completion. We adopted the programming of robots to navigate mazes of varying complexity for this purpose.

Programming the Lego robots used in this study requires—as a minimum for each step—the determination of an action and a vector. The first important variable of task difficulty in this context (Barker and Anson, 2007), we defined as the minimum number of discrete maneuvers required to successfully navigate a given maze. A maze requiring five distinct maneuvers such as a forward move, a left turn, a forward move, a right turn and then a final forward move, we defined as a maze of complexity level five. Our group determined that successfully navigating

this maze would be no different in level of intrinsic difficulty to navigating a maze requiring a right turn, a forward move, a right turn, a forward move and then a left turn. Mazes with differing levels of intrinsic difficulty could therefore be provided for participants to facilitate true comparisons of like with like and to act as the problem specification dependant variable.

Available information was our second design parameter. Any real-world, designed learning or problem solving activity is accompanied by some amount of information about the learning required or the problem to be solved. In the context of the current study we anticipated that the amount of information provided about a maze to be navigated would significantly affect the nature and volume of communication between the two collaborating teams. Tasks of equivalent complexity (intrinsic difficulty) were therefore employed together with task information of three kinds from those deemed relatively rich and complete to those which were relatively poor and incomplete: a scale image of the maze to be navigated together with its specification (numbers and types of maneuver) would be a rich source of information relevant to designing a program to successfully navigate the robot through it. Having an image only would provide less information; whilst having the specification only (for example the unordered number and type of turns and straights) would represent relatively sparse information. Sets of mazes of equivalent complexity were paired for learning/teaching with the participant groups using these three levels of relevant information as the complexity level rose. The ‘available information’ parameter was defined as the communicative constraint imposed upon the problem.

These variables may be related in a mutually inclusive grid and the study presented here focused on the exploration of six cells (Table 2). Ongoing studies are extending exploration into the remaining cells.

High		Image, specification, avatar posture, Mindstorms icon manipulation, in-world chat/text	Image, specification, in-world chat/text	Image, in-world chat/text	Specification, in-world chat/text	In-world chat/text only
Problem specification	Configuration, complexity and sub-task sequence prescribed					X
	Task complexity only prescribed	X	X	X	X	X
	Unprescribed task					
Low	Communication constraint					High

Table 2. Task design matrix showing communication constraint, problem specification and intersection cells explored in the present study.

We applied overarching constraints to interactions between two physically separated teams consisting of two participants during experimental runs. We designed these constraints to encourage more and richer communicative exchanges and encourage questioning, innovative thinking, and hypothesis formation. In one constraint we did not allow students to design mazes with consecutive identical robot maneuvers (e.g. a left turn may not be followed immediately by another left turn). A second constraint was placed on communicative exchanges. In paired runs each team designed a maze of the given level of complexity; then one team first acted as the ‘teachers’ while the other team (the ‘learners’) attempted to create a program to navigate the robot through this successfully. Then teams exchanged roles. For each level of maze complexity all of the communication constraints were applied in sets of paired runs (Table 2). Participants were told that when responding as ‘teachers’ to requests for feedback from ‘learners’ they should respond as helpfully as possible. However, they were not permitted to offer unsolicited information or advice or to reveal the correct action/vector required by the robot at any given point to make further progress. In line with the project’s adopted methodological context, teaching teams were therefore tasked to develop imaginative strategies to help learning teams succeed, but those strategies could not include supplying them with the most productive questions or ‘correct answers’.

We anticipate that from our data, relationships to elements within Bloom's taxonomy will emerge between communicative constraint and problem specification. It seems probable, for example, that the amount of available information about a task of given difficulty may influence the appearance and frequency of different cognitive processes (analyzing, evaluating, etc.) and their application to particular types of knowledge (factual, procedural, etc.). Such relationships could inform metrics for evaluating and designing learning scenarios in immersive virtual worlds, thereby promoting effective learning outcomes by applying certain parameters and constraints.

The data from measurements of flow, video, text/chat, diaries, and interviews is expected to further illuminate the discovered potential relationships and enrich our understanding of how these relationships may correlate to individual and group learning in our collaborative scenarios.

Materials, procedure and data collection

Materials

We used two computer configurations: desktop PCs running Windows XP Service Pack 3, using 3.0 GHz Intel Core 2 Duo processors (model E8400), with 2 GB RAM, ATI X1300 graphics cards, and 17" LCD monitors with screen resolution set to 1280'1024 pixels; and Apple MacBook Pro laptops running OSX version 10.5.X, using 2.26 GHz Intel Core 2 Duo processors, with 2 GB RAM, NVIDIA GeForce 9400M graphics cards, and the 13" inch laptop display set to 1280 x 800 pixels.

We chose Lego Mindstorms NXT software version 1.1 to create robot programs. The design of the robot followed instructions 8527 of Quickstart-Mindstorms (see <http://preview.tinyurl.com/yfw75s2>) and was adopted due to its simplicity and its potential for sensors to be added as the research and task framework is further developed (Figure 2).



Figure 2. Robot design displayed within the Second Life experimental environment.

We used the Second Life interactive 3-D Internet environment to support inter-team communication and record ‘chat’ communication, using a private secure island leased from Linden Labs. Two video cameras were used to record intra-team communication for each of the teams. Additionally, a tailored Visual Basic program was employed to measure flow using Guo and Poole’s (2009) psychometric inventory. Flow, in this context, is defined as ‘a state of consciousness that is sometimes experienced by people who are deeply involved in an enjoyable activity’ (Pace, 2004). The flow scale measures three pre-conditions of flow (clarity of goal; fast, unambiguous feedback; and perceived balance of challenge and skill) and six dimensions of flow (concentration, perceived control, mergence of action and awareness, transformation of time, transcendence of self, and autotelic experience). The scale has good psychometric properties in terms of both convergent and discriminant validity and of reliability (Guo & Poole, 2009).

Procedure

Problem-solving with online communication was studied during the consecutive run of sessions for given tasks. In each session the two teams were located in physically separate computer laboratories within the same building. The teams communicated through Second Life’s chat facility and through the behavior of participants’ avatars in the environment. Each team had to design the course of an identical robot on the floor of their laboratory using adhesive tape. Next, one team’s task was to act as ‘learners’ and create a robot program (using the MindStorms software) to follow the course that the other (teaching) team had designed, drawing on the information provided within the strictures of the communicative constraints being applied. The learning team used the information provided in an attempt to solve the robot-programming

problem. Once the learning team had designed what they judged to be a suitable program, they sent it by email to the teaching team. The teaching team used their robot to run the program on the taped course to establish its success. They were encouraged to offer feedback to the learning team—via the Second Life environment—when the robot executed an incorrect maneuver and to answer any questions posed. However, the communication between the teams was mediated by the protocols pre-set for each experimental run (Table 2) as described above. The implications of this are discussed below.

The cycle of learning and teaching through communication, programming, and testing was repeated. The task was terminated when the teaching team concluded that the learning team's executed program for navigating the designed course was successful, after allowing for uncontrolled variables such as mechanical differences between the two robot devices in traction, drive variability, and other variance due to the manufacturing tolerances inherent in mass produced robotics kits. Then the teams switched roles and the new learning team (the teaching team in the first run) created a robot program to solve the course designed by the new teaching team (the learning team in the first run). Each paired series was run with escalating difficulty; each with all three variants of communicative constraint (Table 2).

Data collection

During each session, the activities and intra-team communication of each team were recorded on video; the inter-team chat communication in Second Life was recorded as a log file in ASCII format; and the robot programs that were created were copied. Additionally, the experience of the members of each team was measured—usually at the end of a session and also sometimes immediately before a break within a session—using the flow scale. Participants also kept a personal diary of their experience of the problem-solving sessions.

Data analysis

Pre-processing of the video recordings of the intra-team communication was necessary to produce data that could be analyzed on all of the computer platforms employed by the research team. We transcribed and stored this communication in word-processed format. We used thematic content analysis (Riffe et al, 2005) to analyze the between-team and intra-team communication data and diary data. We also analyzed the assignments in terms of time-on-task and number of attempts to create a correct robot program. Robot programs were analyzed in terms of their complexity. Flow-scale data were analyzed using statistical techniques.

Process

We followed a well-established process of content analysis for the inter-team communication data (Riffe et al, 2005). First, the content of each participant's verbal report was divided into units of thoughts (Gardial et al, 1994). Each unit is the smallest set of words that are meaningful outside its context, which allows coders to interpret the meaning of a statement without reading the preceding or following text where further division of a unit would render it meaningless. We used Bloom's updated taxonomy (Anderson et al, 2001) to adopt and further develop a coding scheme for the communication in second worlds (Vallance et al, 2010). The following communicative functions were targeted for coding into one or more of the communicative categories:

- independently providing information;
- asking questions;
- confirming information previously provided;
- answering a question with an affirmative statement;
- expressing an observation;
- making a suggestion;
- giving a direct instruction;
- praising;
- making a request;
- answering a question with a negative statement;
- apologizing;
- greeting.

Five independent coders pretested an initial subset of data within these categories using a randomly selected subsample of 10% of the units as training material. We revised the definitions of categories where needed and continued pretesting until intra-team coding was consistent. A second randomly selected subsample was coded and reliability of coding was established calculating the percentage of coding agreement. The process of selecting subsamples and coding was repeated until we reached 90% coding agreement.

We followed the same process for the content analysis of intra-team communication data and diary data. The coding scheme for intra-team communication was developed from Vallance et al's (2009) scheme and the scheme for the diary data was developed based on an initial reading of participants' diaries from which we extracted reflective experience. We used the number of steps in a task to define its complexity. We analyzed psychometric flow data for factor structure using factor analysis and for reliability using Cronbach's alpha reliability coefficient. We calculated correlations with time-on-task, attempts required to create a successful robot program, and robot-program complexity (lines of code) by using validity analysis.

Data matching and cross referencing

For each session, we created displays including course complexity, constraints imposed on communication, the results of content analysis of inter- and intra-team communication per team, flow per participant and per team, time-on-task, attempts required to create a successful robot program, and robot-program complexity. We used both of the allowed within-case displays and cross-case displays for exploratory and explanatory data analysis (Miles & Huberman, 1994). Within-case displays allowed the cross-validation of measures by identification of patterns of association between different types of datum (e.g. inter-team communication and intra-team communication). Using cross-case displays, we established the consistency of cross-validation across sessions by determining to what extent the same patterns occurred over sessions. In addition, we used cross-case analysis to establish the effect of manipulations of course complexity and communication constraints on the different types of datum.

Deriving metrics

Our group derived metrics for each type of datum and made distinctions between measures that were involved in patterns of association discovered in cross-validation and those that were not. The reason for this differentiation was that those measures that were involved in patterns were

considered to show evidence of validity (through association with other measures) or sensitivity (through association with experimental manipulations). Proposed measures of inter- and intra-team communication were the communicative functions (presence or frequency of functions) identified from content analysis. We used measures of flow for dimensions of the flow state scale, and measures of reflective experience for thematic codes (presence or frequency of functions) which we identified from content analysis. Using the thematic coding schemes created in the current study may allow for the development of automatic analysis of (transcribed) communication data and (reflective) diary data stored in digital form. For this aspect, we used taxonomical approaches such as WordNet (Miller, 1995) based on human-coded taxonomies using synonyms and statistical techniques that employ unsupervised machine learning and can reproduce human performance accurately (Landauer & Dumais, 1997). Examples include Latent Semantic Analysis (Landauer & Dumais, 1997), Point-wise Mutual Information (Manning & Schutze, 1999), and Hyperspace Analogue to Language (Lund & Burgess, 1996). Research in other domains has shown that statistical techniques produce more valid results than taxonomic techniques (Kaur & Hornof, 2005; Landauer & Dumais, 1997) although further research, including the present study, may challenge this.

Discussion

The need to promote scientific enquiry among students and the application of approaches that use immersive virtual environments seems likely to grow. However, the use of new technologies needs to be accompanied by clear methods for measuring learning and learning outcomes. Establishing metrics, not only for science learning but also for learning that occurs within virtual environments, is necessary if educators hope to accomplish more than simply using this new technology because it is readily available. This project attempted to explore how learning could be measured while students programmed robots to solve a series of problems. Our initial findings indicate that the development of clear and explicit metrics will be possible but that further research will be needed to ensure their validity.

After agreeing on the design and implementation of the tasks, we made several assumptions:

- that the data sources (text chat logs, video logs of participants, reflective diaries, and interviews) would be sufficient for establishing a series of metrics;
- that the structure of the tasks and their subsequent iterations would be related to the level and nature of communication between team members and teams;
- that by varying task difficulty, constraining communication and the modalities for communicating, a range of strategies for problem solving, negotiation of meaning, communication repair and hypothesis formation would emerge.

These assumptions we found to be generally true; when images of the mazes were provided, team members communicated less with each other and dialogue between teams tended to be limited to defining the parameters of each programming action. Providing only information about the number of turns in the maze, however, increased communication between team members and led to a slight increase in dialogue between teams. When we changed the task either to provide no image, or to give less descriptive help, we experienced a marked jump in intra- and inter-team communication.

However, we observed a number of unanticipated outcomes. One of the most significant outcomes was the variation in the amount of discussion between team members. One team consisted of members who were relatively communicative but had different levels of technical knowledge. A second team consisted of one communicative member with a high level of technical knowledge and another quieter member with limited technical knowledge. While we originally assumed that there would be a disparity in the amount of communication between and within the two teams, the initial review of the video recordings showed that far less discussion took place between the latter team members than was expected. An examination of the text log chats verified this disparity.

The design and completion of the tasks led to constant discussions between the participants and the researchers. While we provided instructions to the participants, they nevertheless consistently asked questions and negotiated for modification of the constraints. This conversational framework (Laurillard, 2002) between participants and researchers occurred on a daily basis and led to modifications not only in the daily tasks, but in the reformulation of the final task as well as changes in the communication parameters. However, the nature of the tasks themselves created a conversational framework between teams. Members of the teams discussed task goals, debated perceptions of their learning goals, took responsibility for directing the focus of the discussions, and provided imaginative feedback to each other (Britain & Liber, 1999).

The tasks also required the participants to take an active role in their learning. The teams of participants received minimal programming instructions for the robots except for a general orientation to the software. They were responsible for learning how to program each step and determining the range of variables to be used. Since each task (except for the final one) consisted of a problem with a set solution, the problem space was limited but contained enough variation for the participants to experiment and formulate hypotheses. This co-construction of programming knowledge between participants enabled them to develop autonomy and not to rely on a teacher or tutor to provide them with guidance. Also, the use of an immersive virtual environment (IVE) created a space that was separate from the shared physical space where the researchers could also be present. We hypothesized that this “spatial differentiation” increased the participants’ reliance on one another rather than a teacher or tutor who would be present in the room. Since the problem and the solution were situated “in world”, and the mode of communication was text chat, participants tended to ask each other questions and solve their own problems before asking a member of the research team for answers.

The basic communication mode of IVEs is text chat, although voice communication is available. When using an IVE such as Second Life, residents/students/learners can define which mode they use and switch between them. This allows educators to either limit learning modalities—for example by only allowing chat—or to increase the range of learning modalities used either by allowing or by requiring both chat and text.

Also, IVEs are virtual 3D worlds with embodied participants represented by avatars who move within a world. This simulation of movement can possibly give advantage to learners who are kinesthetically oriented. One imaginative and unanticipated strategy developed by participants in the present study exemplified this advantage when teams in their ‘teaching’ role made use of

avatar gestures— using feedback to the ‘learning’ team—to signal the required successive robot maneuvers necessary to navigate their maze.

Additionally, artifacts are built and constructed in IVEs, providing opportunities for students who learn through manipulation of objects. These environments provide multimodal learning opportunities that can be incrementally altered, allowing learners not only to use their preferred learning modes and strategies but also to explore and develop the use of new modalities.

Through this project we seek to explore how educational tasks can be designed for different learning objectives. Effective tasks should not only accomplish specified learning goals, but should also provide opportunities for exploration and discovery. At the same time, the tasks must take into account individual differences. Our approach has been to create a set of problems that need to be solved in both the real and virtual worlds. Different learning objectives often require different design components within teaching. Rather than creating unique tasks for multiple learning objectives, we feel it is possible to deploy similar tasks to achieve a variety of goals in immersive virtual environments. For example, if an instructor is interested in maximizing communication, then limiting the amount of provided information may lead to increased negotiation between participants (given an appropriate scenario). If hypothesis formation is the goal, then the instructor may instead need to vary the level of problem complexity.

Conclusions

One of the significant educational benefits of using immersive virtual environments for achieving learning objectives is that they allow individual and cooperative convergence as well as collaborative learning to take place. Learning can occur not only as an individual act of obtaining and deploying knowledge, but also through the co-construction of understanding through participation in a learning community; these aspects are enhanced when students are actively involved in and responsible for their learning. However, the most effective learning is situated in contexts that are meaningful; immersive virtual environments allow educators and educational institutions to create simulations that meet these situations. Creating a relevant and meaningful context is possible in virtual reality by designing a space that best facilitates learning. For example, if students are exploring the concept of acceleration, educators are able to create a virtual laboratory where simulated objects can be observed and measured. However, it is also possible to model otherwise inaccessible objects such as planets or high speed vehicles that move in 3D, and then to change a wide range of variables so that learners can formulate and test their hypotheses under different conditions.

For effective learning and teaching to take place, collaborative learners must be actively involved in meaningful activities that have meaningful contexts. Digital communication has created new opportunities, but often traditional teaching and learning methodologies have been employed without due consideration of their suitability. Teachers and universities should require a theoretical framework to better leverage the benefits and affordances of immersive virtual technologies. The conversational framework, for instance, is an approach that lends itself to networked learning, as do collaborative and constructivist learning models. However, we suggest in this study that approaches employing concepts of task difficulty and communicative richness and constraint must inform metrics to better design and evaluate effective learning within immersive virtual environments. By combining these approaches with Vygotskian social

constructivist learning models and the concepts of purposeful tasks, collaborative learning, and meaningful contexts, educators can develop a more robust understanding of what constitutes effective learning processes in immersive virtual environments and thereby facilitate better opportunities for learning within them.

Initial indications from our data suggest that the nature and defined difficulty of learning tasks can—together with measures of communicative constraint and of the information provided about the task—be used to create metrics for designing and evaluating learning scenarios in immersive virtual environments that can be articulated within Bloom’s revised taxonomy. We propose that the revealed dynamics between these taxonomic elements and the developed metrics will provide insights into the nature of effective pedagogy in these new learning and teaching environments. Such dynamics will facilitate their fuller educational exploitation, especially considering the affordances they offer which are unavailable in more traditional contexts. A subsequent paper will present the completed analysis and derived metrics from our data and discuss the pedagogic model we develop from our experiments.

Ours is an international project involving collaboration between four academics in three Higher Education institutions from two countries with significantly different cultures. The research team’s backgrounds and expertise cover the fields of education, media, psychology, science, and engineering. One of the strengths of such collaborations is the rich experience and diversity that they contribute to the research enquiry. Other strengths are the opportunities they offer for drawing upon a broad sweep of pedagogy, methodology, and social perspective in different environmental and economic contexts which nonetheless broadly share common economic, scientific, engineering and educational aspirations. These projects are not, however, without practical problems in addition to those most immediately obvious as a result of the wide geographical separation of researchers. Additional challenges emerge when creating common research protocols that:

- must function in institutions which apply different procurement constraints;
- use dissimilar and sometimes incompatible IT infrastructures; and
- are driven by policies with very different embedded institutional and cultural assumptions about the nature of academic roles and responsibilities including those towards and for students and research participants.

International research into the effective use of immersive virtual environments, by its very nature, offers the opportunity to annihilate conventional frames of space and time. Such research also involves successfully navigating a combination of real-world and in-world assumptions, limitations, and obstacles while exploiting their many opportunities and resources for exploration, innovation, and progress.

Work proposed for the next phase of our project will not only build upon our existing experimental context to complete the exploration of our task design matrix (Table 2), but will also be developed to target alternative learning scenarios and curriculum areas. This is an attempt to demonstrate the degree of generalizability of our findings, metrics, and proposed pedagogy within the two cultural contexts.

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