Advancing Computational Thinking and Knowledge Development in a 3D Virtual Simulation

M. Vallance

***Abstract*—The paper is a description of the continuing research of the efficacy of a 3D virtual world simulation to support more engaged academic practice and transformative learning in Higher Education. Within the context of a virtual Fukushima nuclear power plant, tasks of quantifiable complexity are designed using programmable robots to engage learners in robot-mediated interactions in both real and virtual worlds. The paper will demonstrate that the use of a 3D virtual simulation to facilitate the collaborative programming of robots provides opportunities for students to engage in professional interactions, constructionist learning, computational thinking and knowledge development.**

Keywords*— *computational thinking; knowledge; learning; constructivism; Oculus Rift; robots; Japan

I. Introduction

The paper is a description of the continuing research of the efficacy of a 3D virtual world simulation to support more engaged academic practice and transformative learning in Higher Education. The multi-disciplinary research is situated in the real-world between researchers at Future University Hakodate, Japan and University of Hull, UK. The project's design and technology development, professional interactions, and collaborative activities are undertaken in a 3D virtual world. Tasks of quantifiable complexity are designed using programmable robots to engage learners in robot-mediated interactions in both real and virtual worlds. By actively participating in international 3D virtual tele-collaboration challenges, which include controlling basic robots within a simulated disaster zone, quantitative metrics of students' programming skills and psychometric assessment of declarative, procedural and meta-cognitive knowledge can be measured.

The paper is organized as follows. First, the developments in cognitive science lay the foundation for innovative academic practice and new, transformative learning. This has been embraced in both UK and USA as Computational Thinking [1]. After that, the project scenario of the 3D virtual world is explained. One motivation of this project is to engage academics and students in Japan with such innovative pedagogical implementations.

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II. Computational Thinking for New Learning

Cognitive science is acknowledged to be the interdisciplinary study of mind and intelligence. It is important as it attempts to explain how the mind works. The central hypothesis of cognitive science is, "Thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures" [2]; the computer analogy being data structures plus algorithms result in operating programs. How the mind works is often explained by cognitive scientists in terms of logic, rules, concepts, analogies, images and neural connections. These are evaluated according to the criteria of representational power, computational power, psychological plausibility, neurological plausibility, and practical applicability [2].

If scientists agree about how the mind works and how we learn, then it stands to reason that those same scientists would teach accordingly. Unfortunately, and common among many university courses worldwide, the processes (the teaching philosophy of instructivism) and product (end of course exams) are more in tune with Watson, Thorndike and Skinner's Behaviourism: "… the only thing we can know with any degree of certainty in the science of psychology is what we can see in the form of observable behaviours" [3]. In other words, traditional, instructivist, behaviorists paradigms prevail, particularly in Japan, despite the recent findings from the field of neuroscience.

For cognitive scientists, knowledge in the mind consists of mental representations that require mental procedures for encoding and decoding messages. This requires a different, less traditional approach to education, its pedagogies, curricula and assessments. Teaching should "create conditions in which learners can construct understandings at levels appropriate to their stage of developmental readiness." [3] as "old disciplinary approaches often foster rigid ways of thinking that are counter-productive for the workers, citizens and persons of today and the near future" [3]. If the more cognitive science friendly approach to education is ignored, and educators adhere to traditional, instructivist, behaviorists paradigms, then the learning capacities of young people will indeed be limited.

A credible approach for teaching a more cognitive science friendly course of study, supported by quantitative and qualitative data worldwide, is called Constructivism. Constructivism supports the active learning processes of accommodation (accepting new experiences) and assimilation (making sense of new experiences based upon what is known). For instance, the aim of any learning situation is to enhance knowledge. Knowledge is not something that can be captured

externally, but is uniquely constructed internally by individuals as each makes meaning of their experiences. Anderson et al's neo-Bloomian taxonomy proposes a hierarchy of knowledge consisting of factual knowledge (relating to a specific discipline), procedural knowledge (techniques and procedures), declarative knowledge (relationship between concepts) and meta-cognitive knowledge (knowledge of demands, strategies and one's limitations) [4].

Constructivism does not prescribe wholly planned strategies of instruction but promotes learning environments that provide opportunities to engage learners in meaning making. Accordingly, technology can be used to promote multimodal, multiple media representations of information that require students to develop multi-literacies for meaningful knowledge development. A number of courses in progressive universities around the world are implemented based upon the theories of multimodality with implementation based upon a social-constructivist approach. There is less of an emphasis on 'learning about' content knowledge but an emphasis on experiences of 'learning in and for' an unpredictable future [5].

To summarize, in constructivist learning students are engaged in active cognitive processing. They are paying attention to relevant incoming information, organising the information into a coherent representation, and then integrating it with existing knowledge. The process requires students to take more responsibility for their own learning by reflecting upon what they have learned and to understand how they learn. These 'habits of mind' can be referred to as meta-learning.

In addition to the theory of Constructivism, research has revealed that effective learning can also be undertaken by implementing a 'Constructionist' environment where students are 'active producers' of learning [6]. Vallance and Towndrow have reasoned that a practical implementation for such active, experiential and multi-disciplinary learning is for students to consider, analyze, solve and make personal meaning from engaging problems [5]. Multi-disciplinary problem-solving presents opportunities for reciprocation between declarative and procedural knowledge in which personal input and collaborative efforts support cognitive connection that in turn can lead to understanding of concepts and theories in multiple contexts (i.e., meta-cognitive knowledge). Additionally, collaborative problem-solving promotes communication involving creative and interpretive meaning-making, analysis and reflective judgment [7]. An approach is required then which encourages exploration, procedural knowledge, iterative, recursive and logical thinking, structured task breakdown, and dealing with abstraction.

These aforementioned active, experiential, multi-disciplinary, problem-solving conditions have been recognised throughout Higher Education by the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE), and are subsequently promoting the inclusion of Computational Thinking (CT): "CT is a problem-solving methodology that can be automated and transferred and applied across subjects" [8]. The UK has taken Computational Thinking further by including it in its 2014 National Curriculum for both primary and secondary schools by introducing a new subject, called Computing, to replace ICT. This compulsory subject has been developed on the supposition that, "Computational thinking is a skill that all pupils must learn if they are to be ready for the workplace and able to participate effectively in the digital world" [9]. Also, in Japan, Wing's seminal Computational Thinking article [1] has been translated and forms the foundation for New Learning (community, pedagogy and curricula) at Future University Hakodate, Japan [10].

Computational Thinking uses a set of concepts, such as abstraction, recursion and iteration to process and analyse data, and to create real and virtual artefacts. It encourages the use of ubiquitous and innovative technologies to solve problems: "Students become not merely tool users but tool builders" [8]. Computational Thinking can accordingly be considered as a device for conceptualizing learning and development with the following characteristics:

- formulate problems in a way that enables us to use a computer and other tools to help solve them;
- logically organize and analyse data;
- represent data through abstractions such as models and simulations;
- automate solutions through algorithmic thinking (a series of ordered steps);
- identify, analyse, and implement possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; and
- generalize and transfer this problem solving process to a wide variety of problems.

In summary, constructivism acknowledges the diversity between learners and their varying cognitive developmental stages. The 'one-size-fits-all' approach to Higher Education has to change to meet the demands of a wider range of occupations in an uncertain future. Taking into account the findings from cognitive science, Higher Education pedagogy, curricula and assessment need to be transformed, not systematically revised. It is reasoned that Computational Thinking offers a framework upon which to design new, transformed learning opportunities. The next section will summarize a longitudinal research attempt to implement Computational Thinking and knowledge development supported by a constructivist approach in the new domain of a tele-collaborative 3D virtual simulation.

III. Fukushima Nuclear Power Station Scenario as a 3D Virtual Simulation

Computational Thinking explicitly expresses multi-disciplinary content and contexts for student tasks. This research project has been developed on the rationale that due to advances in computer technologies, educators can now consider a wider range of problems and extensive solutions, which can be implemented in both real and virtual spaces. In addition, Barr and Stephenson point to successful projects that have involved simulation and robotics [8]. For instance, beginner programming concepts can be introduced and experienced using the graphical Mindstorms software developed by LEGO and National Instruments which has been

shown to support programming through its drag-and-drop graphical user interface [11].

Closed and highly defined tasks provide the necessary comparability and empirical data to determine the success of task completion. To satisfy these criteria, the programming of a robot to navigate mazes of measurable complexity can be adopted [12]. Research can be designed to observe students communicating in a 3D virtual world the programming of a robot to follow distinct challenges which, in turn, results in tangible and quantifiably measured outcomes. LEGO EV3 Mindstorms robot programming components can be used to quantify task complexity and thus iteratively increase the challenges given to high school and under-graduate university students. A 3D virtual simulation provides interesting, engaging, realistic yet safe contexts where robots are ordinarily utilized; i.e. disaster recovery situations. A virtual simulation also allows remotely located students to enter as avatars to communicate and collaborate with other students. Data within world can also be easily captured for analysis [13].

Metaverse designers have created a virtual Fukushima nuclear plant for the researchers using the Unity 3D application. The 3D space replicates the real-world Fukushima reactors with cooling towers prior to the disaster of March 2011. It is anticipated that such user-accessible simulations with citizens controlling the virtual robot will create an awareness and understanding of disaster recovery, and not simply rely upon retrospective information from unprepared experts. Consequently, as well as capturing data for analysis of cognitive processes, an affective aim is to familiarize students and the public with the complexities of nuclear power; given that there is much confusion about the situation at present in Japan. The pedagogic rationale is to combine a 3D simulation space for real world collaboration; in this case, the programming of robots contextualized by simulating a robot navigating within a restricted area.

Students maneuver a virtual robot using the built-in controller to pick up radioactive bins (see Figure 1). A radiation meter in the bottom right corner indicates radioactivity levels that provide a clue as to the nearness of the radioactive bins. A rear-view mirror for the robot controller is viewed in the top right corner. A birds-eye view is offered via a virtual drone that can be maneuvered over the abandoned space, seeking out the location of the radioactive bins. If the robot crashes, then the radioactive bins explode. In addition, after a 6-minute interval the tsunami alarm is activated and the area will flood (see Figure 2).

The project has also been developed to be viewable via the Oculus Rift 3D head-mounted display (see Figure 3). Future commercial developments in 'virtual reality' technologies will enable users to login to online 3D virtual spaces to engage and collaborate with other participants remotely located. Technologies not only include head-mounted displays exemplified in this research by the Oculus Rift, but also immersive virtual reality environments known as CAVE (Cave Automatic Virtual Environment). The maturation of immersive technologies has profound implications for the design and implementation of Higher Education and its subsequent pedagogies, curricula and assessments.

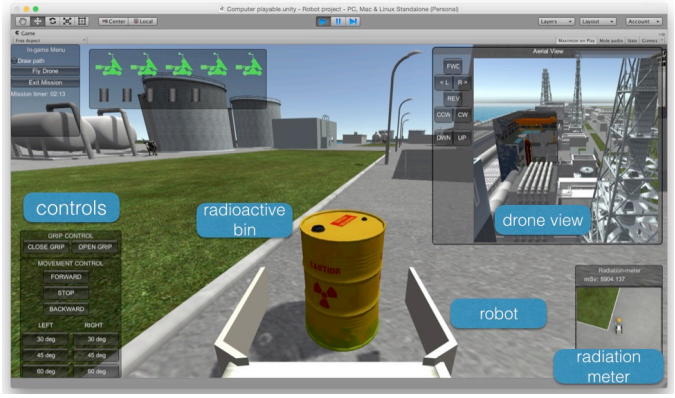

Fig. 1. Virtual Fukushima interface

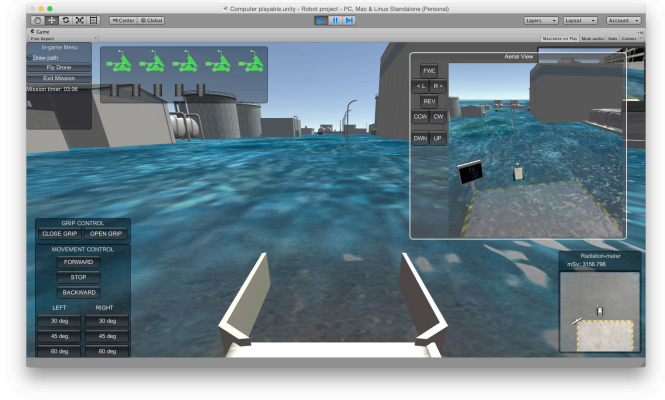

Fig. 2. Tsunami flooding

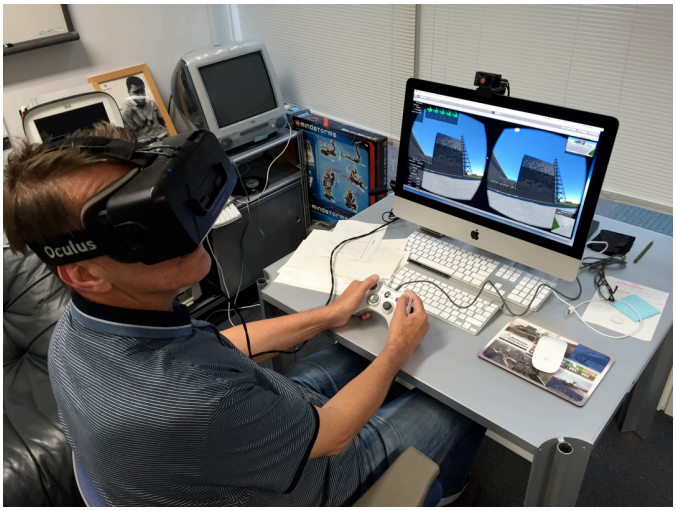

Fig. 3. Manouvering robot using Oculus Rift

The enactment of Computational Thinking in this project is summarised in Table 1 [5].

TABLE I. ENACTMENT OF COMPUTATIONAL THINKING

Computational Thinking	Enactment
Formulating problems in a way that enables us to use a computer and other tools to help solve them.	Disaster recovery is an abstract concept for most people who have never experienced catastrophe such as a tsunami or a nuclear power plant failure. One way to visualize and gain secondary experience of a disaster is through a virtual simulation. The problems can be replicated or hypothesized using virtual 3D spaces linked to real-world, physical artifacts thereby creating challenging scenarios to be solved. 3D technology, physical robots, and programming as the computer interface were used for technical communication.
Logically organizing and analyzing data.	Challenge data such as Circuit Task Complexity, solution data as Robot Task Complexity, and Task Fidelity were used to quantify task challenge and students' skills.
Representing data through abstractions such as models and simulations.	There was an iterative design of the tasks; in other words, the data from a task was used to inform the complexity of the next task. The context of the new task was determined and then presented as a simulated task challenge.
Automating solutions through algorithmic thinking (a series of ordered steps).	The graphical interface of the LEGO Mindstorms programming software as blocks to be manipulated necessitated a logical, ordered approach towards a solution. Likewise with the LabView software used during the more challenging tasks.
Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.	The students were not given a programming task but were provided with a problem and a context. For example, one early task was to locate a radioactive barrel in a simulated disaster area, determine an effective circuit to maneuver to the barrel and return it to a safe area. From this experience students then replicated the circuit in the real-world lab, added appropriate sensors to the LEGO robot, and programmed it to collect an object and return it to a specified location.
Generalizing and transferring this problem solving process to a wide variety of problems.	The students used their knowledge of program sequencing and then applied to a partial LEGO device called a BrickPi robot. This is a combination of LEGO, the Raspberry Pi computer and a PCB interface (the BrickPi). The students maneuvered the robot and activated its sensors using the Python programming language. The experience of transfer supports students in their attempts to manage complexity and abstraction.
Reflecting on learning experiences through feedback.	After each task the students discussed their problem-solving strategies, the communication successes and deficiencies, and their programming skills. Personal notes were kept along with goals for the next task. The UK teacher utilised the Welsh Bacalaureatte Essential Skills assessment to monitor the students' progress and provide formative feedback.

IV. CONCLUSION

It is acknowledged that learning is an extremely complex process that occurs within the learner, is unobserved, occurs in random and chaotic ways and is a response to a personal need and, often, occurs to resolve some ambiguity. It is associated with making new linkages in the brain involving ideas, emotions, and experience that lead to new understandings about self or the world. It is reasoned that a 3D virtual world as a simulation for collaborative efforts can result in measurable learning outcomes. Research into the efficacy of online 3D virtual collaborations for effective learning must therefore be persevered in order to determine its value to educators and promote new, transformative learning in Higher Education. Moreover, if the promotion of Computational Thinking across disciplines is desired by Education authorities, as shown in the initial section of this paper, there needs to be a transformation in academic practice which is informed by the research in cognitive science. To reiterate and conclude this paper, for Computational Thinking and 3D virtual worlds to transform education, quantifiable metrics of learning are required. Much more work needs to be done.

ACKNOWLEDGMENT

The research was supported by JAIST kakenhi [grant number 15K01080].

REFERENCES

[1] Wing, J. M. Computational Thinking. *Communications of the ACM,* Vol. 49, No. 3, p.33 (2006)

[2] Thagard, P. *Mind: Introduction to Cognitive Science*. USA: MIT Press p.10 (2005)

[3] Kalantzis, M. & Cope, B. *New Learning: Elements of a Science of Education*. Cambridge, UK: Cambridge University Press p.199, p.205, p.71(2012)

[4] Anderson, L.W., Krathwohl, D.R., Airasian, P.W., Cruicshank, K.A., Mayer, R.E., Pintrich, P.R., Raths, J. & Wittrock, M.C. *A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman (2001)

[5] Vallance, M & Towndrow, P. Pedagogic transformation, student-directed design and computational thinking. *Pedagogies: an international journal,* Vol. 11, No. 3 (2016)

[6] Harel, I & Papert, S. (Eds.) *Constructionism*, Norwood, USA: Ablex Publishing (1991)

[7] Tarricone, P. *The taxonomy of metacognition*. New York: Psychology Press (2011)

[8] Barr, V. & Stephenson, C. Bringing Computational Thinking to K-12: What is Involved and What is the Role of the Computer Science Education Community? *ACM Inroads,* Vol. 2, No. 1, pp. 48-54 (2011)

[9] NAACE Computing in the national curriculum. Available from http://www.computingatschool.org.uk/data/uploads/cas_secondary.pdf Accessed October 20, 2014. (2014)

[10] Nakashima, H. Computational Thinking. Japanese translation. Vol. 56, No. 6, June 2015. Available from https://www.cs.cmu.edu/afs/cs/usr/wing/www/ct-japanese.pdf Accessed December 29, 2015 (2015)

[11] Lui, A. K., Ng, S. C., Cheung, H. Y & Gurung, P. Facilitating independent leaning with LEGO Mindstorms robots. *ACM Inroads*, Vol. 1, No. 4, pp. 49-53 (2010)

[12] Barker, S. B. & Ansorge, J. Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research in Technology and Education*, Vol. 39, No. 3, pp. 229-243 (2007)

[13] Vallance, M., Martin, S. & Naamani, C. A situation that we had never imagined: post-Fukushima virtual collaborations for determining robot task metrics. *International Journal of Learning Technology*, Vol. 10, No. 1, pp.30–49 (2015).