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VRMath: Knowledge Construction of 3D Geometry in Virtual Reality Microworlds

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ABSTRACT
Because of the complexity of 3D geometry (e.g., 3D transformations) and the constraints in our real environments (e.g., body movement and manipulation of objects), most young children have difficulty in learning 3D geometry concepts and processes. Therefore, in order to address this issue, a prototype virtual reality learning environment (VRLE) named VRMath that set out to enable children to move in, manipulate objects, and construct programs to create objects in a 3D environment was designed and evaluated. The design of the HCI components of VRMath was influenced by educational semiotics [2, 5], which *connect* mathematical meanings with multiple semiotic resources. The evaluation, which involved six children, focused on both the design of VRMath and the learning within VRMath. Many new ways about thinking and doing 3D geometry and issues about the usability of VRMath were identified during the evaluation. These have implications for learning within and design of VRLEs.

Author Keywords
Virtual Reality Learning Environment (VRLE), Semiotics, 3D Geometry, Logo, Microworld.

ACM Classification Keywords
H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems; H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

CONTEXT
There are many powerful information communication technology (ICT) tools for facilitating the learning of geometry. For example, the Logo programming language [6] has geometrical semantics for the linguistic formalisation of mathematics and links symbolic representations to visual turtle graphics. Cabri-Géomètre and Geometer's Sketchpad utilise mouse dragging to directly manipulate geometrical objects that bridge the gap between static drawings and dynamic figures [4]. These ICT tools, however, operate in 2D environments. Therefore, the number and types of 3D concepts and processes (shape, position, and direction) that can be investigated in these environments are limited. To overcome this limitation and because of VR's potential in education [8] , VRMath was designed to provide children with a wide variety of 3D geometry experiences.

RESEARCH DESIGN
This research study was framed within the design-experiments methodology [1], which is commonly used in educational contexts particularly in evolving (engineering) technological learning environments. Design-experiments methodology shares some common features as of Participatory Design (PD) methodology [7], in which the students, teachers, and field experts (end users) are actively involved in the assessment, design and decision-making processes of the learning environment (system). However, it differs from PD as it deals with the dynamic nature about learning where researching problems and goals emerge; and the development of theories about learning (cognition) and the design of learning environment progress together during the processes of design experiments. Based on design-experiments, this research study has an iterative cycle consists of four stages: development of conceptual framework, design of prototype VRLE, enactment and evaluation of the VRLE, and reflection and redesign of the VRLE.

Conceptual Framework
The conceptual framework to inform the design of VRMath was derived from an analysis and synthesis of the research literatures from learning theories (psychology), technology, philosophy of mathematics, and semiotics. Key notions from the field of educational semiotics provided the glue that integrated various aspects of the conceptual framework. The following key HCI components of the conceptual framework were derived from the field of educational semiotics:

- Meaning-making occurs in the sign process, which is the interaction among sign, object, and interpretant [2].
- There are three categories of sign: icon (the sign imitating the object visually, e.g., an image of an apple), index (the sign referring to the object by the attributes of the object, e.g., smoke refers to fire), and symbol (the sign referring

to the object by rule or convention, e.g., language) [2] that can be considered for the computer interface design.

- A sign is only an incomplete representation of the object [2]. Therefore, multiple semiotic resources that include topological (meaning by degree; continuous representation, e.g., visual graphics, colour, and size), typological (meaning by type; discrete representation, e.g., word and symbol), and social-actional (meaning occurs in doing or making things in real world setting with other people), should be integrated for meaning-making [5].

The Prototype VRLE

From the conceptual framework, the researcher designed the prototype version of VRMath (see Figure 1), which included three interfaces: VR, programming, and hypermedia-forum.

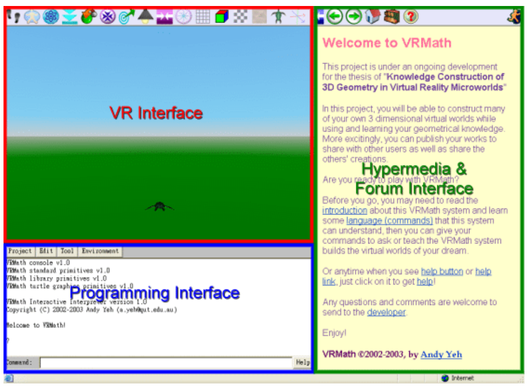

Figure 1. The prototype VRMath

The VR interface is mainly a topological resource that provides visual and continuous representations of 3D geometry. The programming interface is an important typological resource that has a Logo-like language with an extended set of 3D related commands to provide symbolic and discrete representations of 3D geometry. The hypermedia-forum interface is a type of social-actional resource that provides a channel for cooperative work and collaborative learning within a forum community. Through the interactions within and between these three interfaces, users are able to build and manipulate 3D virtual worlds by means of using language and communicating with peers while constructing 3D geometry knowledge (and improving their spatial abilities).

Results from the Enactment and Evaluation of VRMath

Six primary students (Grade 4-5) were involved in the enactment and evaluation of VRMath. They interacted with nine learning activities designed for VRMath. The primary findings regarding both the design of VRMath (HCI issues) and the learning of 3D geometry were that:

- VRMath was easy to learn, use and remember, and the participants felt comfortable when interacting with three interfaces.
- Navigation within the VR space using mouse and keyboard was facilitated with the integration of navigation aids (e.g., restore viewpoint, compass, grid, etc.) into the design of the VR interface.
- Use of programming language was facilitated by the integration of GUIs (e.g., a procedure editor, a graphical command centre, etc.) into the design of the programming interface.
- Construction of 3D geometry concepts and processes such 3D mental rotation (e.g., turn, tilt and roll), relationship between components of various common solid shapes (e.g., vertices, edges, surfaces) was noted during the children's interaction with topological, typological, and social-actional semiotic resources of VRMath.

CONCLUSION

A semiotic approach to inform HCI design is not a new idea (see for example [3]). However, in this study an educational semiotic rather than a traditional engineering semiotic approach was utilised to inform the design of a VRLE. The findings from the enactment and evaluation of the prototype version of VRMath indicate that an educational semiotic approach may be a most productive paradigm to inform the design of HCI components of VR learning software.

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