"Come take the pilot seat!" Learning interactions in a virtual solar system

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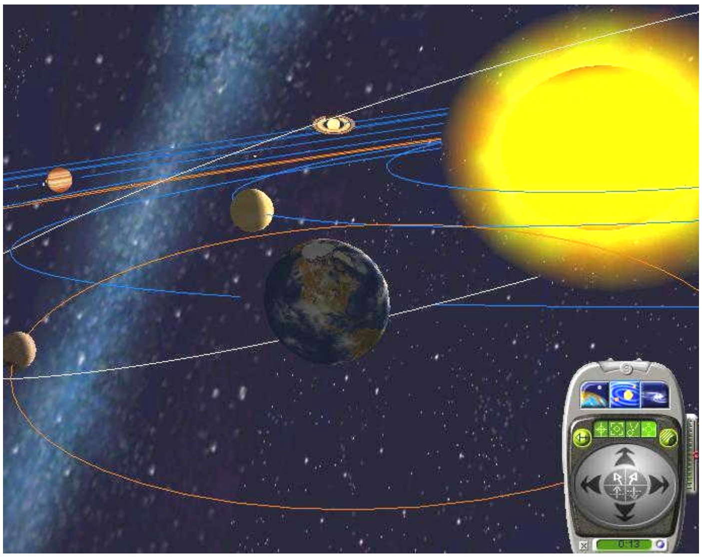

This study examined the learning dynamics of high-school students while they explore a Virtual Solar System (VSS). The VSS is a 3D virtual environment based on real NASA planetary images. Each learner uses the computer screen as a "spacecraft's window" to observe the system's objects by changing its frame of reference and selecting different view modes. A coding scheme based on the Observer™ software was design to capture and analyze the learning interactions from micro and macro perspectives, and to visualize its evolution over time. The findings show that each student created his own unique learning pattern within at least five different dimensions (cognitive, affective, navigation, interface and scaffolding). The construction of meaning emerged in a non-linear pattern which includes transitions between and within these dimensions. Design principals of future virtual learning environments for supporting effective and enriching learning experiences are discussed.

Theoretical Background

Many educational virtual reality environments (VEs) have been developed to support scientific learning. Winn (1993) suggest that VEs afford a new type of direct learning, which enhances the learners' motivation and their knowledge acquisition. Recently, Dede *el al*., (2005) found that the use of a MUVEE called River City, increased students' motivation and engagement in the learning activities, improved students' attendance and decreased students' disruptive behavior.

Virtual Reality (VR) is defined in Encyclopedia Britannica as "The use of computer modeling and simulation to enable a person to interact with an artificial three-dimensional visual or other sensory environment. VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information" (VR, Britannica 2005).

The simplest form of virtual reality is a three dimensional image that can be explored interactively at a personal computer, usually by manipulating keys or the mouse. These kinds of VR environments are called "non-immersive" VR environments. "Immersive VR environments" include Head Mounted Display (HMD), gloves and other hepatic accessories or CAVE displays which constitute a full "immersive" experience for the user. Steuer (1995) noted that many definitions of VR refer to specific technologies without taking into account the user. Therefore, he defined "Virtual Reality" as: "A *real or simulated environment in which a perceiver experiences telepresence"* (Steuer, 1995, 34).

The term "telepresence" include both teleportation and the experience of "presence" the generic perception of "being" in an artificial or remote environment in virtual environments. Furness *et al*., (1997) put a special focus on the general potential benefits of using VEs for teaching and learning complex scientific concepts, stating that: "VR *improves learning, when it does, by providing the learners with new, direct experiences of phenomena they could not have experienced before, either in direct interaction with the real world or using other technologies".* (Furness et al., 1997, p. 7).

Additionally, Furness *et al*., (1997) suggested that VEs are engaging and seductive, and can support the teaching of complex topics with less need to simplify them. In a VE learners can easily and without effort visit places and view objects from different points of view, and can manipulate variables that cannot be manipulated in the real world.

However, only few studies systematically examined the real-time learning in VEs (Barab *et a*l., 2002; Keating et al., 2002).

The Virtual Solar System (VSS) designed by Yair *et* al., (2001) is a non-immersive three dimensional simulation, based on real NASA images taken form various spacecraft missions. It was developed as a part of a novel learning environment for studying astronomy through a joint effort of the Center for Education Technology (CET) and the Tel-Aviv University.

The VSS is a major component in the ″Touch the Sky Touch the Universe″ CD-ROM, which was originally developed for the Israeli educational system. Newer version of the software includes a "fly-over-terrain" above the Lunar and Martian surfaces. The VSS shows the planetary objects as they revolve in their orbits against the constant background of the Milky Way and the stars. The Solar

System was scaled-down while the Keplerian motion was kept at the correct relative rates. The computer mouse interface is used to change one's viewpoint while "flying" in a 3D space. The user has a navigational "remote control" with arrows to steer and change the orientation in 3Dspace. The VSS allows new learning experience which has not been systematically studied yet.

Research goal and questions

The main goal of the current study was to describe and analyze the learning interactions of high-school students' while they explore the Virtual Solar System (VSS) for the first time.

The research questions were:
What are the characteristics of the student's learning interactions during the VSS' free exploration task and how does the scientific conceptual understanding regarding the solar system as a complex system develops in real-time.

Methodology

To meet the study goals, a microdevelopment approach was used to examine the learner's real-time interactions (Granott & Parziale, 2002). Microdevelopment focus on the real-time patterns of change in abilities, knowledge, and understanding occurring in short time spans.

Data Collection and analysis

Nine 10th grade students (5 boys, 4 girls) aged 15-16 years old volunteered to participate in the study. Their overall grades were above the average (B and higher). The study was conducted at the university lab in the form of individual session, lasting between 1.5-2 hours each. Prior to the first session, each participant was shown a four-minute introductory video, displaying the main features of the VSS. The participant was instructed to freely explore the VSS, for as long as s/he liked. The session was followed by an interview. Participants' real-time actions together with what they said were captured directly from the computer screen.

After extensive, repeated viewing of participants' observable actions together with what they said, a coding scheme was designed. Each participant's action was coded within one-tenth of a second resolution by using the Observer™ software (Noldus et al., 2000).

Results

The videotapes were transcribed and an inductive thinking-aloud protocol analysis was performed in which patterns, themes, and categories of analysis were extracted. Coding the think-aloud protocols of the participants yielded 1423 items. Following an extensive protocol analysis, five dimensions were defined (interface, navigation, cognitive, affective, and support seeking) and each verbal sentence was classified to one of them accordingly. Three different types of learning interactions patterns were observed (superficial, local object-oriented, and a flexible object-system).

In order to reveal the dynamics of the learning interactions which evolved over time, a sequential analysis of the verbal expressions was performed. The analysis revealed two major patterns in the microdevelopment of participants' scientific understanding: (1) the non-linear process construction of meaning included transitions between and within dimensions, (2) the development of a scientific understanding of the solar system as a complex system emerged in a fluctuating pattern.

Figure 1: Two different learning trajectories during the free VSS exploration task

Fig 1a: DO's object-oriented learning interaction pattern

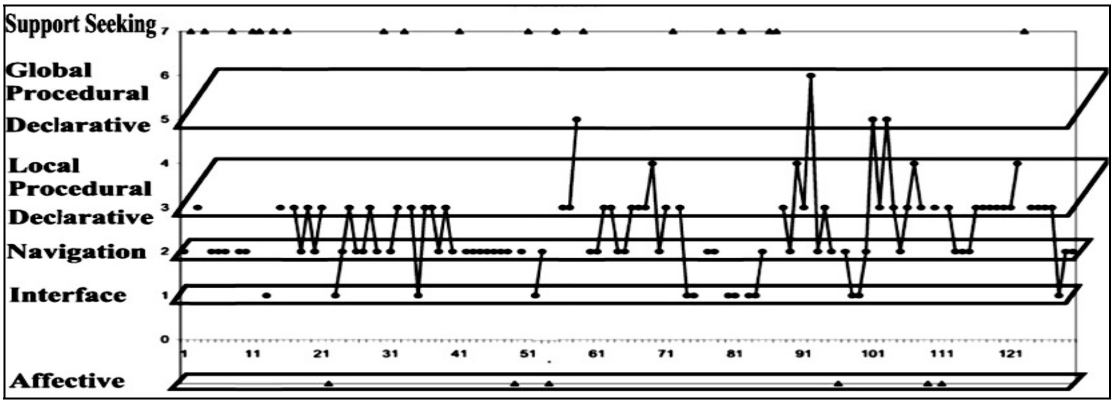

Fig1b: MI's **flexible object-system learning interaction pattern**

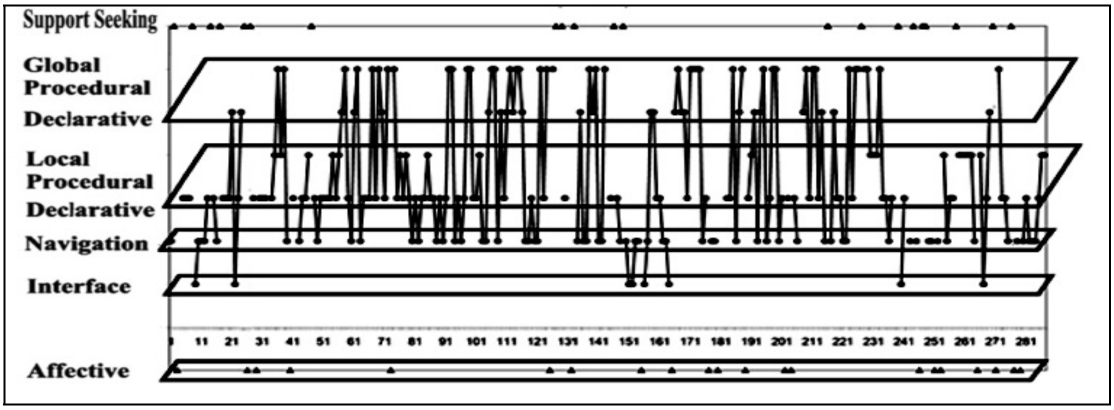

Figure 1 shows two participants' real-time microdevelopment trajectories when performing the VSS free exploration task. Each point within the graph represents a verbal phrase.

The X-axis represents the phrase's ordinal number along the timeline. The upper graph shows DO's (boy, age 16 years 5 months) object-oriented learning interaction pattern in which DO mainly shifts between a single planetary object and the navigational dimension. The lower graph demonstrates MI's (girl, age 16 years 2 months) flexible object-system learning interaction pattern. MI frequently shifted her frame of reference, moving between local-global cognitive dimensions, in both declarative and conceptual levels. These trajectories demonstrated that taking an active role in the “pilot seat” is very demanding with respect to navigating and orientating in a 3D space.

The affective-cognitive interplay

A systematical examination revealed two types of cognitive-affective interplay: The "enhancement" effect involved the joy of discovering new facts, “aesthetic joy” and “existential feelings”. The opposite “disengage” effect consisted of long durations of frustration that resulted mainly from navigational and interface usability problems. Figure 2 shows the frequencies distribution of the seven main affective categories (*n* = 67) across participants’ relative timeline.

Figure 2: Frequencies distribution of the main affective categories across the participants’ task timeline (*n* = 67)

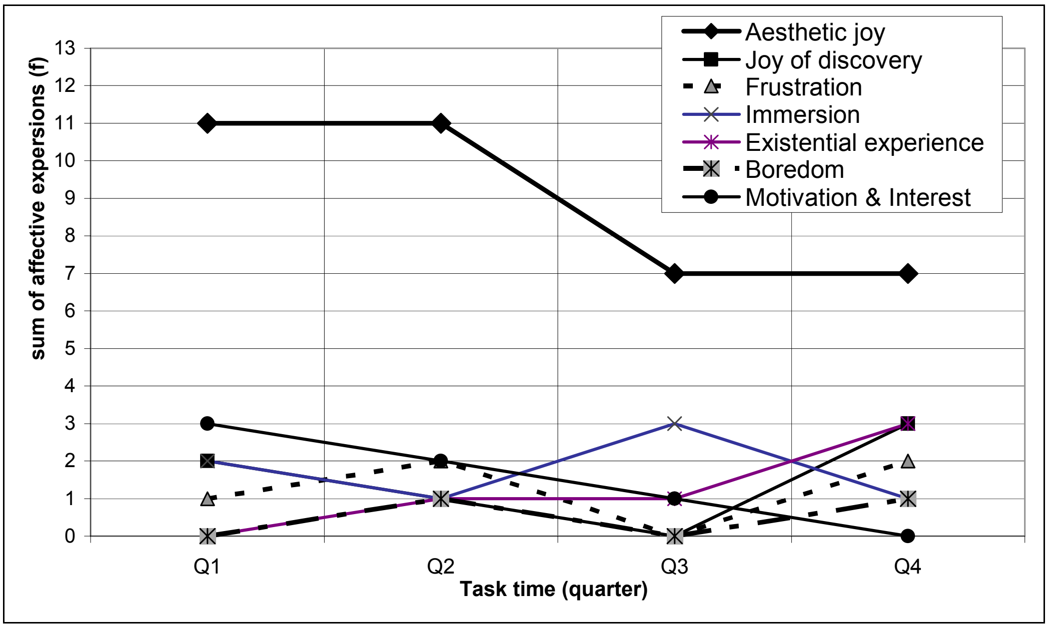

Fig. 2 shows that the enjoying the beauty of the scientific phenomena was the most frequent during the first two quarters of the session. During the third and the fourth quarter of the sessions the overall frequencies of all sentences were reduced, but remained relatively high compared to sentences relating to the other affective categories. The frequencies of the “disengage affective” expressions such as boredom or frustration were relatively low throughout the session. The participants’ frustration expressions were found to accompany navigation and orientation difficulties. Nevertheless, all nine participants claimed that taking an active role as "pilots" instead of being passive observers, was the most motivational factor for learning. All nine participants also reported a sense of being “immersed” within the VSS.

The support seeking dimension

During the sessions, the participants felt free to ask for support. The frequencies distribution of the four main support seeking categories (*n* = 187) is plotted on the quarterly timeline (See Fig. 3).

Figure 3: Frequencies distribution of the four support seeking categories, across the participants' task's timeline (n = 187)

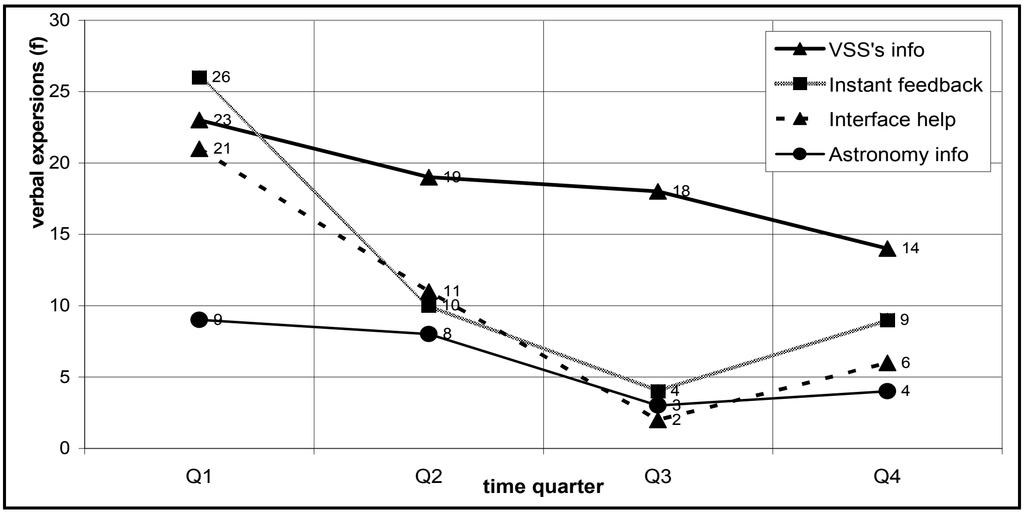

Figure 3 demonstrates that as expected, there has been a decline over time in requests for technical support (the dotted line). The frequency of questions relating to the VSS's representations remained relatively high in the second and the third quarters of the session. Requests for instant feedback were most frequent. The analysis showed that taking the "pilot seat" is a complex task in which gaining total control over the learning interaction process is accompanied by a high frequency of support seeking requests.

Discussion and instructional design implications

Overall, the findings show that exploring the VSS served as an enriching learning experience. First, the results show that constructing meaning by interacting within a virtual reality environment is a highly complex process. Empirical studies of this complexity would meet the challenge of developing a coherent learning theory in VEs for exploiting its educational potential. Second, the three different exploration patterns described above demonstrate that providing a flexible, open, constructivist learning opportunity does not necessarily results a high level of conceptual understanding. The VSS's unique features might have increased individual differences in the learning interactions, as learners created their own path according to their personal internal tendencies. Third, the learning within virtual environments included a complex interplay between the affective and cognitive dimensions. One pedagogical implication for teachers could be, paying attention to possible "affective pitfalls". Introduction tutorials which focus on the unique VSS features, a well-planned interaction with a teacher or a built in smart agent could assist the learners in taking the "pilot" role in the exploration journey. Yair *et al*., (2003) suggested a structured mediation process based on a "Thinking Journey" metaphor, by which teachers can guide their students in using the VSS to explore the Moon and Mars. Additionally, the design of future dynamic digital learning environments should address individual differences by providing appropriate flexibility and an intelligent built-in feedback feature which affords real-time peer interactions. Finally, the design of large-scale virtual environments should be accompanied with intuitive navigation tools to enable effective orientation and navigation. All of the above could assist students in building a more sustained and deep scientific understanding of the subject matter at hand.

To conclude, we hope that our learning interactions multi-dimensional analysis could serve other related research areas which study interactions in virtual environments that represent complex scientific and professional domains, such as training simulations and digital game-based environments, to name a few.

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Acknowledgements

This work was supported by a grant from the Sakta-Rashi Foundation for Doctoral Science & Technology Education Excellence awarded to the first author.