An Empirical Examination of Feedback: User Control and Performance in a Hapto-Audio-Visual Training Environment

Dawei Jia; Asim Bhatti; Saeid Nahavandi; Douglas Creighton
Center for Intelligent Systems Research (CISR), Deakin University
dwj@deakin.edu.au; asimbh@deakin.edu.au; nahavandi@deakin.edu.au; dougc@deakin.edu.au

Abstract. Utilising advanced technologies, such as virtual environments (VEs), is of importance to training and education. The need to develop and effectively apply interactive, immersive 3D VEs continues to grow. As with any emerging technology, user acceptance of new software and hardware devices is often difficult to measure and guidelines to introduce and ensure adequate and correct usage of such technologies are lacking. It is therefore imperative to obtain a solid understanding of the important elements that play a role in effective learning through VEs. In particular, 3D VEs may present unusual and varied interaction and adoption considerations. The major contribution of this study is to investigate a complex set of interrelated factors in the relatively new sphere of VEs for training and education. Although many of the factors appears to be important from past research, researcher have not explicitly studied a comprehensive set of inter-dependant, empirically validated factors in order to understand how VEs aid complex procedural knowledge and motor skill learning. By integrating theory from research on training, human computer interaction (HCI), ergonomics and cognitive psychology, this research proposes and validates a model that contributes to application-specific VE efficacy formation. The findings of this study show visual feedback has a significant effect on performance. For tactile/force feedback and auditory feedback, no significant effect were found. For satisfaction, user control is salient for performance. Other factors such as interactivity and system comfort, as well as level of task difficulty, also showed effects on performance.

1. INTRODUCTION

In recent years, there is a clear trend of utilising advanced computer technologies for training and education at all managerial levels and functional areas. One such technology, the virtual environment, is perceived to be effective in enhancing a person's ability to learn abstract concepts and complex procedural tasks. VE is usually used synonymously with Virtual Reality (VR), which is also known as artificial reality and cyberspace. In contrast to other instructional mediums that rely heavily on visual information displays, VEs achieve advantage by delivering visual, auditory and force or tactile feedbacks in an intuitive, interactive and engaging manner. They also allow the presentation of multiple sensorial information with timely feedback. VEs have been widely adopted as training tools, facilitating users in learning procedural tasks across disciplines as diverse as engineering, aerospace, and medicine. However, there remains a need to gain a better understanding of user adoption and acceptance, as well as design principles to fulfill VE potentials. This study investigates user perceived feedback, perceptions of self control and performance over procedural task learning in hapto-audio-visual environments.

1.1 Hapto-audio-visual environment

Hapto-Audio-Visual (haptic + audio + visual) interfaces involve the integration of visual, audio and haptic displays, which present information to the user through the human visual, auditory and haptic systems [1-3]. This information is perceived to enhance a user's spatial awareness, interaction and sense of control in task performance, and a user's sense of immersion and presence. They often utilise special equipment such as a head mounted display (HMD) for visual display, stereophonic headphones for auditory displays and a tactile device for haptic displays. These immersive VEs provide a greater range of interaction and user experience than traditional 2D user interfaces (UIs) can offer. For instance, VEs allow display of mixed modalities to engage human perceptual, cognitive, and communication skills to process the scenario being presented in a virtual world [4].

1.2 Effective design VEs for training

Learning and training are complex but complementary processes. When practical skills are to be acquired, such as object assembly operations [5], training must be realised. For effective learning, the system must stimulate motivational learning factors in order to engage learners and focus their attention at a suitably high level. In particular, nontraditional and interactive graphical forms of learning materials or data may leverage 3D colour graphics and animations that match users' interests and increase their learning motivation.

Researchers, including Pearce [6], have suggested that computer-based learning programs can be designed to respond appropriately to a user's inputs and the interactivity of the learner can be stimulated by the design. In addition, it is can be easier to predict and control the behaviour of a computer-generated environment than rather human behaviour for the learning purpose [7]. The constructivist view of learning suggests that learners need to process information actively in order to learn. In VEs, the learner or user constructs their understanding through physical activity and direct manipulation, often requiring effective utilisation of muscle, skeleton joints, and limbs of body [8], which can induce implicit and explicit learning modes. Such active engagement promotes cognitive activity that results in constructivist learning [9]. These activities are accompanied by visual instructions, audio and haptic feedback.

2. CONCEPTUAL DIMENSIONS

2.1 Feedback

Feedback is considered a primary instructional strategy and a powerful component in learning. It can be defined as “the provision of knowledge of progress to be used in adjusting subsequent behaviour, and is a fundamental element for any adaptive system or organism” [10 (p.3)]. Importantly, feedback acts both to inform the recipient of expected behaviours and to provide information for satisfactory performance outcome. In the present study, training involving procedural knowledge and motor skill acquisition is delivered by a hapto-audio visual environment, which requires high level cognitive activities. Extrinsic feedback is provided by the VE and examined through gaining insight of users perceptions of the design efficacy and how well various system feedback facilitate or impede learning. In this sense, feedback relates to information that is sent back to the user about what action has been accomplished through the use of a system input/output device [11, 12].

2.2 Learner/user control

Learner control refers to the amount of influence a person has over the learning environment, and may include control over the content, presentation of an instructional experience or selection of tasks that differ in their structural features [10, 13]. Research suggests individuals differ in cognitive styles. Some may prefer to have control over learning media and materials, while others may prefer not to be in control [14]. Instructional design and training literature suggests that learning program enable optimal learner control allows learners to make selections according to their current knowledge, interests, and preferences, which is likely lead to positive learning outcomes, motivation and satisfaction [10]. Having control over the learning materials may hamper learning and motivation in situations where learners or users are novice in a domain [13]. Nevertheless, it is commonly recognised that having sense of in control potentially lead to beneficial effects on learning and motivation. As most users are “novice” to the VEs [1], the learner or user often give less control in modifying the learning environment or selection of tasks or learning procedures. The important aspect of learner control, in the context of this research, is a users’ feel of being control of the VE, i.e. the degree of user control of various system and user interface components to accurately manipulate virtual object via direct interaction with the system to successfully accomplish training tasks.

2.3 Satisfaction

Satisfaction is a widely accepted attribute of usability in any research involving human interaction with computer technology. Higher satisfaction is indicative of a user interface that is usable, user-friendly, and functioning well. It has been recognised as the largest single key factor that influences the users’ acceptance and adoption of computer technology. In the learning context, satisfaction has been used widely as a key factor in assessing the effectiveness of learning programs [10, 15]. Enjoyment reflects the user’s feeling of pleasure or contentment during the VE experience, and is often associated with satisfaction [16]. Also, appropriate feedback allowing users to engage in the learning activity at a level that suits their own cognitive processes will result in a higher level of satisfaction [10].

2.4 Performance

In the area of haptic user interface, effectiveness and efficiency of haptic systems are often assessed according to either the performance of the haptic interface or the haptic feedback perceived by human users [17]. Measuring the performance of the haptic user interface is often performed throughe algorithm-based validation and comparison-based rendering realism, whereas measuring haptic feedback perceived by human users comprises of methods for psychophysical evaluation of haptic user interfaces [18]. Many human factor studies have been applied to both assess the performance of haptic user interfaces and user perceived haptic feedback in sensory-motor control tasks, such as peg-in-hole, tapping, targeting, haptic training, as addressed in [17]. In the present study, performance was measured both objectively on participants’ behaviour or real time task performance, and subjectively on user perceptions of a hapto-audio-virtual environment (see Section 3).

2.5 Cognitive load

Cognitive load reflects a multidimensional construct representing the load that performing a particular task imposes on the learner’s cognitive system [19]. It often serves as an indicator of the level of information being manipulated in working memory and directly measured using self-report instruments (e.g. NASA-Task Load Index) or indirectly measured using dual task techniques at a given time to explain the cognitive capacity for learning. In this research, cognitive load relates to both physical load and mental load the user perceives while performing tasks in the VE. VEs, as complex and advanced visualisation systems, convey large volumes of information that can place high cognitive loads on the users. If visualisation techniques embedded in a VE do not convey information effectively, then its usefulness is questionable, and may lead to poor performance and error [20].

2.6 The present study

The cognitive, skill-based and affective learning outcomes [21] are extended in this study to include constructs of key measurement dimensions of performance, user perceptions or preferences and affect. Such extension is useful, as 3D VEs encompass many of the same adoptions as traditional 2D user interfaces (e.g. perceived ease of use, perceived ease of learning and satisfaction) and design concerns (e.g. usability, learnability, and fidelity). Nevertheless, due to the unique characteristics of VEs, it presents unique user adoption and design concerns that need to be addressed unambiguously. In addition relationships between feedback, satisfaction, and performance remain to be answered on procedural knowledge and motor skill acquisition in VEs.

3. METHOD

Undergraduate, postgraduate students and academic staff (N=76; 56 male and 20 female) of four age groups, 18-24 (N=32), 25-34 (N=33), 33-45 (N=8) and over 46 (N=3) from the School of Engineering, Deakin University participated in this study.

3.1 Material and measures

Hapto-audio-virtual environment

A haptically enable VT system [2] was utilised in the study. The system was designed to support the learning process of general assembly operators as well as provide an intuitive training platform to enable assembly operators to learn, repeatedly, until the operators are proficient with their assembly tasks and sequences. The system hardware includes I/O devices (Phantom® haptic device, 5DT® data glove, Flock of Birds) and visualisation equipment(Emagin's Z800 HMD and Stereo projectors). System software is responsible of providing interactive functionality to the user. The 76 volunteers trailed four modes of training modes in the VE, completing a series of object assembly operations: (1) Mode I – 3D Animated Simulation explaining the task procedures and sequence of operations required to be followed by the user to achieve a successful assembly; (2) Mode II– Experimental learning with a simple object assembly task, which enables the user to interact with the VE through first-person experience; (3) Mode III – Interactive simulation of assembly operations, which allows the user to go through the training tasks in a pre-defined sequence where each task needed to be performed in a specific order; and (4) Mode IV – Self-exploratory of assembly tasks, which offers the user with freedom to practice the required skills without any restriction of task sequence. Mode IV allows ‘learning by doing’ in a repeated manner and logs the performance information of the user for evaluation.

Performance test

In performance tests, each participant was expected to accomplish seven object assembly tasks within a 15 minute time limit. During the test, the VE system automatically logged the participant’s performance for each task, including time on task and error rate. The log file recorded experiment details, allowing more accurate performance evaluation, through tracking time requirements (in seconds) and accuracy (completion rate) that each participant needed to complete the performance training tests.

User perceptions of VE

Various evaluation methods for usability can be performed through *Analytic evaluation*, *Evaluation by experts* or *Evaluation by users*, which deal with performance information about the interaction, the effectiveness of the interaction, or the user feedback data about the interaction, respectively [22]. The present study focuses on user feedback data about system design efficacy, perceived control, satisfaction and cognitive load. A self-report user perceived VE efficacy questionnaire (PVE) was designed for this purpose. A 7-point Likert scale was used to gather participants’ rating for each item, from 1 (Very strongly disagree) to 7 (Very strongly agree). Specifically, 3 items were designed relate to visual, auditory and tactile or force feedback evoked by the VE. Users rate their perception in terms of appropriateness and usefulness of the feedback. In addition, 6 items were developed to measure user satisfaction on “system comfort”, “user experience”, “system design”, “fidelity”, “learnability” and “training” construct. Furthermore, 3 items were designed for users to report the degree of cognitive load they experience. One item was on physical load, another one was on mental load. The third item was on the adequacy of time to complete training task. User control feedback data was gathered in the interview section (see Section 3.2).

3.2 Procedure

Upon entering the experimental environment, each participant was given a brief introduction about the purpose of the experiment, the VE training system, the experimental procedure and their rights. A Pre-training questionnaire designed to collect the participant’s demographic information (e.g. age, gender, prior experience etc.) was then filled out. The participant then went through four training modes (Approximately 30 minutes). 5 minutes break was introduced between the training mode II and III, and between III and IV to minimise the potential VE exposure impact. A training test was then introduced to the participants. At completion, a post test questionnaire designed to collect the participants’ perceptions of the system efficacy, was introduced, followed by a short interview section with the participant about his or her feelings, emotions, perceptions of the training and learning experience. This was to gather a snapshot of the participant’s feeling at a time when they just experienced the virtual training. The entire experiment including the training sessions last about 1.30 hours. User task performance session and interview were video recorded for later review and playback.

4. RESULTS

4.1 Performance test results

Table 1 shows the task completion rate in the VE training test section. 75 participants successfully completed one or more assembly tasks (T1 to T7) at various level of difficulty (Low to High) within 15 minutes. T1 of low level of difficulty has the highest completion rate. On the other hand, T7 of highest level of difficulty was completed by only 27 participants. In addition tasks T2 to T6 of moderate level of difficulty have completion rate range from 53 to 71. Overall participants showed high level of object assembly skills after training in the VE (M=77, SD=24, N=75).

Table 1: Performance test result

Object Assembly Tasks	Level of difficulty (LOD)	Completion rate (N=75)	Time on task (in seconds)
1 Fix radio box	Low	75	36.21
2 Drill in screw bolt1	Moderate	71	27.69
3 Drill in screw bolt2	Moderate	67	20.29
4 Drill in screw bolt 3	Moderate	64	12.97
5 Drill in screw bolt 4	Moderate	64	25.86
6 Fix stereo	Moderate	53	31.88
7 Fix power connector	High	27	152.04

It is also apparent that participants spent average of 36.21 seconds on the first, lowest task difficulty level task (T1). The time to complete T1 is higher than the time that participants spent on completing tasks at moderate level of difficulty (T2 to T6). Also participants spent less than half of the time in completing T4 than T1. An average of 27 seconds was spent on completing the task with the highest level of difficulty (T7). It is also apparent that task completion rate, was much higher for the task with low level of difficulty in contrast to difficult task. Mixed results were achieved for tasks with moderate level of difficulty, with completion rate range from 53 to 71.

4.2 Feedback

As Figure 1 indicates visual feedback that induced from HMD received highest rating in terms of quality of feedback.

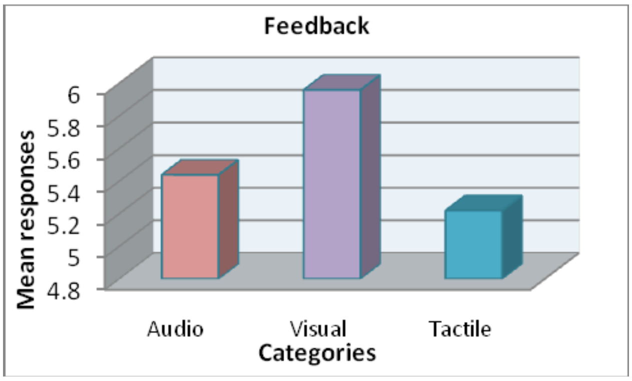

Figure 1: Feedback

Users mean rating result M= 6 (Strongly Agree) suggests majority users felt visual feedback e.g. color change of the object was appropriate and useful to assist them in manipulating virtual objects. Overall, users agree both audio feedback and tactile or haptic feedback e.g. force sensation were appropriate and did not distract them from performing the task.

4.3 Satisfaction

Overall users seem satisfied with their learning experience, system design and training in the VE, with all satisfaction rating close to or above 5 (Agree), as Figure 2 illustrates. In particular, 'user experience' received highest satisfaction rating among other criteria. Learnability of the VE was also perceived to be satisfactory. When asked if the haptic device, data glove, 3D mouse and HMD were comfortable to operate together in unison i.e. 'system comfort', majority users agree, with mean rating close to 5.

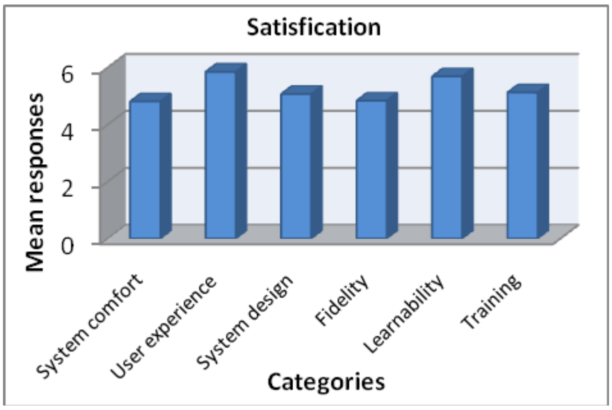

Figure 2: Satisfaction

In terms of enjoyment as Figure 3 illustrates, out of 45 responses, 67% (N=30) of the participants enjoyed their experience or having fun learning in the VE 31% (N=14).

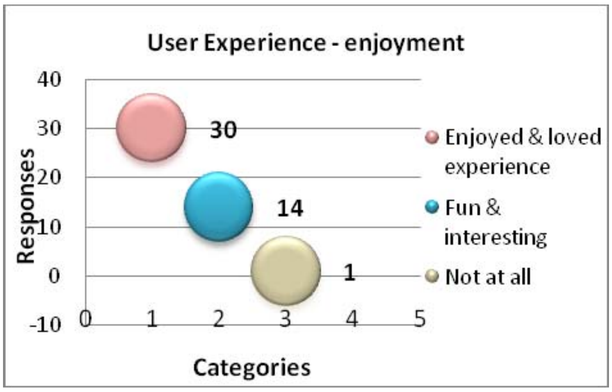

Figure 3: Enjoyment

"Enjoyed", 'loved it", "fun" "very exciting" are some of the words used in describe the feeling of learning in the VE, which indicates the VE is replica a 'real world' learning environment, as users comments: *"I enjoyed it very much and did the test with pleasure"; "It is interesting, user may felt the real assembly environment via this training" and "It was interesting and provided as enjoyable insight into [the] haptics".*

4.4 Cognitive load

Although participants agree (M=5) that they did not feel pressured to complete the task within allocated time, overall participants seem unsure if they felt physical or mental overload by participating training in the VE. Review video transcript enable a better understanding of the issue, as some users reported discomfort that due to physical overload, for instance, “Shoulder did become fatigue by beginning evaluation for a period of time” and “ feeling pain in my arm”.

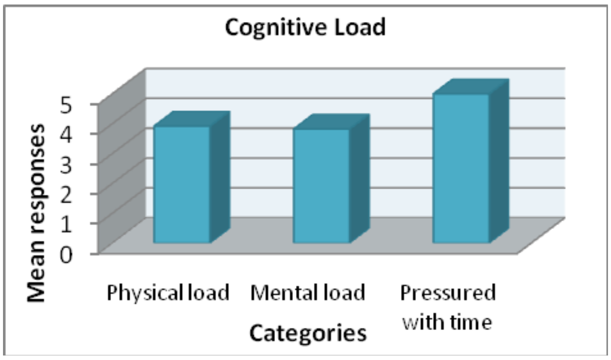

Figure 4: Cognitive load

4.5 User control

Careful review of video interview transcripts revealed that 15 participants felt in complete control at the whole time. 7 participants felt “mostly” in control, and only one participant reported ‘mostly’ felt not in control. Difficult in rotating object, not enough time on training, haptics device is too flexible and lack of stability are some of the reasons made participants not in complete control. Level of task difficulty also contributes to degree of user control. For instance, some participants felt in complete control, apart performing the last task that of highest difficulty level. To complete the task, require participants have high proficiency in control of various input devices to rotate, manipulate the smallest objects and move around it within the 3D virtual world. It is evident from the results that perception of interactivity between the participant and the VE, and feeling of in control influence their overall perception of VE efficacy. Feeling of in control also is an indicator of one’s confidence in performing task [6]. In other words, it is most likely that higher level of feeling of in control is associated with one’s task performance outcome. Problems that participants’ encounter that made them feel less in control are likely contribute to poor performance outcome, which deserve attention.

5. DISCUSSION

5.1 Effect of feedback

Past research shown external feedback would not affect procedural knowledge acquisition in online learning situation, and argue that intrinsic feedback may affect procedural knowledge acquisition [10]. We do not know these findings hold in VE training situation. A regression test was performed to examine the effect of various feedbacks on performance and satisfaction. Results shown overall feedback had significant effect on performance, F (2.9, 1571) = 3, p<.05. Post hoc tests using Turkey’s HSD revealed that visual feedback from HMD had significant effect on performance (β=-0.357, p=0.016). On the other hand, tactile/force feedback (β=-0.31, p=0.824), and audio feedback (β=-0.068, p=0.639), had no significant influence on performance. In addition, no effect of cognitive load (β= 0.033, p=0.519) on performance was found. Interestingly, satisfaction with the input tool (haptic device, data glove and 3D mouse were comfortable to operate together in unison) lead to a significant effect on performance (β=0.313, p=0.024).

5.2 Design enhancement

Screening 30 video interview transcripts and 58 survey responses of open-ended questions provided us with useful insights about the effective aspects of the VE design as well as the areas that require improvements. 39 participants responded to the question regarding the better design of the virtual training system. 4 participants believed the VE is perfect that nothing needs to be done to enhance the efficacy of current design. Among the other 35 participants, only 2 participants felt improve user comfort will improve the current design. Another 11 participants had diversified suggestions, which related to issues less reprehensive of the current usability problems. In terms of graphical visual effects, some suggest “[current design] ideal for training, but little more graphics and visual effects would add to [more] attraction”. In terms of data glove, users comment *“improvement needed in glove interface, need more sensitivity*”, *“perhaps the movement of the glove could be more flexible, I felt a little restrictive with the [haptic] grabber”.* Interestingly, the two users’ feedbacks of design improvement related to 3D mouse were not directly on the current interface, but relate to training time (“*3D mouse, I think it's kind of cool. I just want more practice”*), and preference of the user (*“[regular] mouse control is better”).* This consistent with the users feedback that no difficulties were experienced during interaction and training in the VE system related to 3D mouse.

5.3 VE efficacy

Additionally, 7 out of 47 participants perceive the efficacy of the VE is high as they did not find any negative aspect of the VE. Only 2 of the 47 participants perceive the realism of the VE is low. On the other hand, 8 participants perceive the realism is high and claim this is a positive aspect of their user experience with the VE. Also mixed result of the utility of haptic device and HMD were found in this study. Data glove and 3D mouse achieved higher user acceptance, adaption and rating compare with haptic device and HMD, with less user experienced system deficiencies been reported related to these system components. In addition, results suggests when design 3D hapto-audio-visual environment, it is essential to ensure appropriate and adequate visual feedback, and user comfort to maximum learning. As cognitive load is not always explicitly perceived by users, separately access physical load can be examined indirectly by observation and self-report on ergonomic issues such as discomfort. Also VEs need to be designed to promote cognitive strategies through involving challenging tasks and arouse curiosity, which may enhance immersion and presence of learner [23].

6. CONCLUSION

This study examined various modes of feedback induced by a hapto-audio-visual environment as a primary instructional strategy and a powerful facilitator in learning. Through user subjective perceptions and objective performance outcomes, this study explicitly addressed a complex set of interrelated factors for the first time. This study has shown that VE feedback has a significant effect on performance. In particular, visual feedback was shown to contribute performance the most, compare with tactile/force feedback and auditory feedback. User control is salient for performance and satisfaction. Other factors, such as interactivity, system comfort, and level of task difficulty, were also recognised of contributing effects. This study provides insight into the relationships between the perception measures and performance measures for assessing hapto-audio-visual environments.

ACKNOWLEDGMENT

This research was fully supported by the Centre for Intelligent Systems Research (CISR) at Deakin University.

REFERENCES

1. D. A. Bowman, E. Kruijff, J. J. LaViola, and I. Poupyrev, *3D User Interfaces: Theory and Practice*. Boston: Addison-Wesley/Pearson Education, 2004.
2. A. Bhatti, S. Nahavandi, Y. B. Khoo, D. Creighton, J. Anticev, and M. Zhou, "Haptically Enable Interactive Virtual Assembly Training System Development and Evalaution," in *The Annual Simulation Technology and Training Conference (SimTecT2009)*, Adelaide, Australia, 2009.
3. P. Boulanger, G. Wu, W. F. Bischof, and X. D. Yang, "Hapto-Audio-Visual Environments for Collaborative Training of Ophthalmic Surgery Over Optical Network," in *IEEE International Workshop on Haptic Audio Visual Environments and their Applications (HAVE)*, Ottawa, Canada, 2006, pp. 21-26.
4. M. Turk and G. Robertson, "Perceptual user interfaces," *Communications of the ACM,* vol. 43, pp. 33-34, 2000.
5. D. M. Popovici and A.-M. Marhan, "Virtual Reality-Based Environments for Learning and Training," in *Product Engineering: Tools and Methods Based on Virtual Reality*, D. Talaba and A. Amditis, Eds. Dordrecht, Netherlands: Springer Netherlands, 2008, pp. 123-142.
6. J. M. Pearce, "An investigation of interactivity and flow: student behaviour during online instruction," in *Department of Information Systems*. vol. Doctor of Philosophy Melbourne: The University of Melbourne, 2004, p. 342.
7. W. Winn, "Learning in artifical environments: Embodiment, embeddedness and dynamic adaption," *Technology, Instruction, Cognition & Learning,* vol. 1, pp. 87-114, 2002.
8. X.-D. Yang, W. F. Bischof, and P. Boulanger, "Validating the Performance of Haptic Motor Skill Training," in *Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems*, Reno, Nevada, USA, 2008, pp. 129-135.
9. R. E. Mayer, R. Moreno, M. Boire, and S. Vagge, "Maximizing Constructivist Learning From Multimedia Communications by Minimizing Cognitive Load," *Journal of Educational Psychology,* vol. 91, pp. 638-643, 1999.
10. L. Chai, "To Have or Have Not: An Examination of Feedback, Learner Control and Knowledge Type in Online Learning," in *The 36th Hawaii International Conference on System Sciences (HICSS'03)*, Hawaii, 2003, p. 6a.
11. D. Stone, C. Jarrett, M. Woodroffe, and S. Minocha, *User Interface Design and Evaluation*. San Francisco: Morgan Kaufmann Publishers, 2005.
12. M. Virvou and G. Katsionis, "On the usability and likeability of virtual reality games for education: The case of VR-ENGAGE " *Computers & Education,* vol. 50, 2006.
13. G. Corbalan, L. Kester, and J. J. G. van Merrienboer, "Dynamic task selection: Effects of feedback and learner control on efficiency and motivation," *Learning and Instruction,* vol. 19, pp. 455-465, 2009.
14. M. Whyte, D. Karolick, M. Nielsen, G. Elder, and W. Hawley, "Cognitive Sytles and Feedback in Computer-assisted Instruction," *Journal of Educational Computing Research,* vol. 12, pp. 195-203, 1995.
15. R. A. Noe, "Trainees' attributes and attitudes: Neglected influences on training effectiveness," *Academy of Management Review,* vol. 11, 1986.
16. J. J. W. Lin, H. B. L. Dhu, D. E. Parker, H. Abi-Rached, and T. A. Furness, "Effects of Field of View on Presence, Enjoyment, Memory, and Simulator Sickness in a Virtual Environment," in *IEEE Virtual Reality*, 2002, pp. 164 - 171.
17. S. Ricciardi, M. Nappi, L. Paolino, M. Sebillo, G. Vitiello, G. Gigante, D. Pascarella, L. Travascio, and A. Vozella, "Dependability issues in visual-haptic interfaces," *Journal of Visual Languages & Computing,* vol. In Press, Corrected Proof, 2009.
18. H. Bleuler, E. ASamur, F. Wang, and U. Spacelter, "Generic and systematic evaluation of haptic interfaces based on testbeds," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, Los Alamitos, Claifornia, 2007.
19. D. Windell, E. Wiebe, S. C. Lane, and B. A. Beith, "A comparison of two mental workload instruments in multimedia instruction," in *The Human Factors and Ergonomics Society 50th Annual Meeting*, Santa Monica, 2006, pp. 1764-1768.
20. H. K. Padda, A. Seffah, and S. Mudur, "Towards a Metrics-Based Framework for Assessing Comprehension of Software Visualization Systems " in *Human Interface and the Management of Information: Methods, Techniques and Tools in Information Design*. vol. 4557/2007: Springer Berlin / Heidelberg, 2007, pp. 335-344.
21. K. Kraiger, J. K. Ford, and E. Salas, "Application of Cognitive, Skill-based, and affective theories of learning outcomes to new methods of training evaluation," *Journal of applied psychology,* vol. 78, pp. 311-328, 1993.
22. L. Leventhal and J. Barnes, *Usability Engineering, Process, Products, and Examples*: Prentice Hall, 2007.
23. R. Moreno and R. E. Mayer, "Interactive Multimodal Learning Environments," *Educational Psychology Review,* vol. 19, pp. 309-326, 2007.