Measuring Students' Learning and Task Performance Using Semantic Multi-Modal Aids in Virtual Assembly Environments

Sehat Ullah
Department of Computer Science & IT, University of Malakand, Dir (L), Pakistan
sehatullah@hotmail.com

Abstract-Learning and performance improvement during procedural task realization in Virtual Reality (VR) environments can be enhanced using different types of cognitive aids. Previous work in literature stressed on task learning (with performance drop) or vice versa. In this paper we propose the concept of semantic aids to be systematically used in virtual environments to increase user performance as well as learning, A Guided Virtual Reality Training System (GVRTS) is used for the assembly of three phase step-down transformer in the experimental study. Group1 (20 students) used direct cognitive aids (change in color of object candidate for selection, blinking arrow showing final position, a color line bar under the object pointing to its accurate placement). Group2 (20 students) are trained with GVRTS where direct cognitive aids plus visual semantic aids are provided, group3 use direct plus audio semantic aids, and group4 (20 students) use direct aids plus audio and visual semantic aids. A comparison based on task performance, resulted in less performance drop in case of group2, group3 and group4 as compared to group1. Experimental results also revealed that semantic aids considerably improved learning and knowledge transfer to the real world.

Index Terms—virtual Reality, Virtual Environment, Semantic Aids, Multi-modality, Interaction Based Learning

I. INTRODUCTION

HUMAN use various sensory channels to acquire knowledge and perform different tasks on its basis during their lifetime for existence. They are always in search of how to know and interact with their environment/surrounding. Learning can be divided into two categories i.e. Task learning and Task related theory learning:

· Task learning

Task learning is related to the practical performance of a task e.g. to assemble a three phase step-down transformer, initially the user needs to identify which part to be chosen, how to pick a part, how to transfer it from source to destination, how and where to place it. The most important is the order of steps to be carried out.

- Task related theory learning

This kind of learning is related to the theoretical aspects of the task. For example to carry out the assembly of a three phase step-down transformer, the knowledge about the name, type, function of various parts of the transformer and their relationship with each other.

Regular guiding instructions of a skilled trainer are necessary in performing the task precisely and timely. This sort of training which is supervised by a trainer is always desirable for learning of cognitive and motor skills . Acquiring knowledge through real world approaches is difficult because of high cost, non-availability of devices and limited space . In addition the availability of expert trainers, time limitation and danger to human health also minimize the usefulness of real world training approaches [i]. To overcome these challenges, Virtual Environments (VEs) can be of vital importance in training and learning activities .

Virtual environments are computer generated worlds that mimic the real world situations and permit user to interact with virtual entities in real time. For training users in different areas such as medical, military and education, these environments can be efficiently used. VEs become more valuable when augmented with cognitive guidance specially multi-modal guidance which is provided to users during task realization [i-ii] . Cognitive load theories [iii-viii] and multimedia representation principles [ix] also support the same perceptions. Various types of instruction/guidance aids such as audio, visual, haptic, or simple instruction manuals may be used for this purpose. The audio aids might be the oral directions of the trainer, manual may be in the form of an instruction guide, visual aids may include a blinking arrow over the object or change in color. Similarly haptic aids may be the attractive force towards the target object. On the basis of provided information, these aids may be divided into two types: direct and indirect aids .

Indirect aids: These are implicit type of information/aids such as instruction book, manual, charts, maps, verbal/gestural instructions of a trainer, provided to assist trainees in performing a task. It does not provide any direct clue for the trainee in the training environment. In indirect aids during performance of the task, the trainee needs mental translation of the available information which results in increased mental burden [ii]. For guiding trainees in an assembly task [i]. used instruction book.

Direct aids: These are explicit type of information/aids such as color, arrow, haptic force etc. provided by a system to assist trainee in performing a task. The use of direct aids during the task operation produces little or no mental overhead on the trainee due to straight forward nature of the guidance cues. Direct aids offer simple and valuable information in a simple style to accomplish the task. Three different types of navigational guidance aids (arrows, compass, and lighting source) were used by [x] to help users in finding the target objects in a virtual environment. Navigational guidance aids (arrow and tracer) were provided by [xi] to assist users in the exploration of a VE. [ii] argued that direct aids allow little exploration as well as it reduces transfer of knowledge in to real environment due to dependency on the training environment.

This paper investigates the hypothesis that if semantic aids are added with direct aids, it will lead to enhanced learning/exploration and higher student's performance in the virtual training environment along with improved knowledge transfer into real world environment.

The hypothesis is experimentally tested using a three dimensional (3D) guided virtual reality training system (GVRTS). GVRTS is a desktop based virtual assembly environment. The students perform the assembly task using experimental conditions i.e. direct aids and different semantic aids. Following are the objectives of the work:

- To examine the effect of using semantic aids with direct aids on students' learning.
- To investigate the effect of audio, visual and their combination with semantic aids on task performance.
- To investigate the effect of semantic aids on knowledge transfer to the real world environment.
- To investigate the effect of GVRTS on the acquisition of technical skills.
- To investigate the application of technical skills gained through GVRTS in real world environment.

In section 2 related work is presented, section 3 explains GVRTS, section 4 presents guidance, section 5 is related to experiments and evaluation and section 6 presents result analysis. Conclusion and future work is finally described in section 7.

II. RELATED WORK

In 1980, VR started to be used in training and education.

Different VR based education projects such as Global Change, Science Space, Virtual Gorilla Exhibit, Cell Biology, Atom world, and many other being introduced in 90's . Now VR is the most attractive research area in teaching and training.

Various virtual learning environments (VLEs) have been developed in different areas such as for routing and designing of cable [xiv], power system operation [xv], mathematics [xvi-xvii], physics [xviii-xix], Radioactivity [xxi], assembly planning and training [xxvi], medical education [xxvi] and biological education [xxvii-xxviii] etc.

In educational virtual environments different researchers proposed various types of guidance techniques in literature. For guiding users in a virtual environment, [x] used three different kinds of guidance aids (lighting source, compass, and guiding arrows). They found that compass and arrows are better than lighting source [xi] compared a VLE based on navigational guidance aids (arrows and tracer) with a non-guided VLE. The results showed that VE supplemented by guidance aids (arrows and tracer) produced improved learning as compared to non-guided VE. [xxix] used an Augmented Reality (AR) image based instruction system for the assembly operations of a Fun Train on a desktop computer. Here the guidance aids were in the form of texts, labels and arrows. Assembly operations in the form of video clips were also used for guidance.

For guiding users in a path navigation task, Kuang et al. used virtual fixtures as guidance cues. They performed the task using virtual fixtures with haptic and without haptic guidance. Here virtual fixtures plus haptic guidance aids showed good results as compared to the graphics only fixtures used for path representation. In path navigational tasks virtual fixtures offers substantially good performance results on the basis of speed, accuracy, or both . Rosenberg developed a 3D teleoperation environment for peg-in-hole task in which he used haptic and aural virtual fixtures. The use of virtual fixtures improved performance by 70% as compared to no virtual fixtures in the experimental study. For guidance of surgeon's tools in tele operated coronary bypass, [xxxv] used a virtual wall on mammary vein in tomography image. The use of virtual wall removed the tours outside the preferred areas and reduced the completion time about 27%. In a collaborative virtual environment [xxxvi] examined user performance, co-presence and cooperation using haptic guides. They found better results in using haptic guides in terms of performance, awareness, and co-presence. [ii] compared verbal guiding instructions with verbal guiding instructions plus pointing of the target position on a screen using a mouse. The environment was a 3D virtual puzzle game. The use of guidance based on mouse pointing reduced cognitive load [xli] on learner but at the same time reduced performance significantly.

A 3D haptic VE is presented by Rodriguez et al. that was used for the assembly of a Lego helicopter. The assembly consisted of 75 sequential steps. Two types of guidance aids were used in the VE. In the first case indirect aids were provided using an instruction book which consisted of 75 images of all steps. In the second case direct aids were provided via changing the required object color and a copy of the object over the final position in a controlled fashion. Then the assembly was performed in real world. Experimental comparison showed that the controlled use of direct aids doesn't degrade knowledge transfer from virtual to real environment.

Gavish et al. developed IMA-VR system. The system used haptic and visual aids as guidance cues. In haptic aids attraction force towards the target point/object were used. Visual aids were provided using highlighting object, displaying copy of object at destination point, and color change of object. The next step to be taken was represented using the appearance of a blinking circle at that point. According to them it is essential to give more information to learner to produce good metal model of the task, but there is little exploration in direct aids along with dependency on the training system which reduces transfer of knowledge into real world . For building a mental model of the task which results in independent performance of the task, high exploration is very essential . It is also needed for problem solving and error dealing in 3D environments.

We will use semantic guidance to improve learning while availing the high performance of direct aids and to ensure maximum knowledge transfer to real environment. We will use GVRTS, a 3D VE for experimental purposes. ARToolKit markers [xl] (as shown in Figure 1) will be used for interaction with the system.

Fig. 1 . Example of ARToolKit markers’

III. GUIDED VIRTUAL REALITY TRAINING SYSTEM

GVRTS is a 3D desktop based VE for assembly. Its purpose is to train students in the assembly task of a three phase step-down transformer.

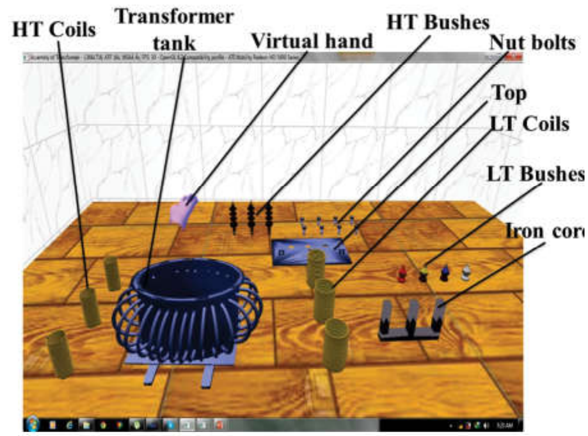


Fig. 1: GVRTS and its main components

The structure of GVRTS is shown in Fig. 2. The 3D environment along with all transformer parts are designed using 3DS Max to achieve good quality with increased realism. All the models are placed after loading in the virtual environment. The system allows user to navigate, select, and manipulate the parts in a realistic fashion.

ARToolKit markers (printed patterns) are used for interaction (with six degree of freedom) with the system. The complete system model is shown in Figure 3. The complete working mechanism of GVRTS is described in the model along with all its basic modules.

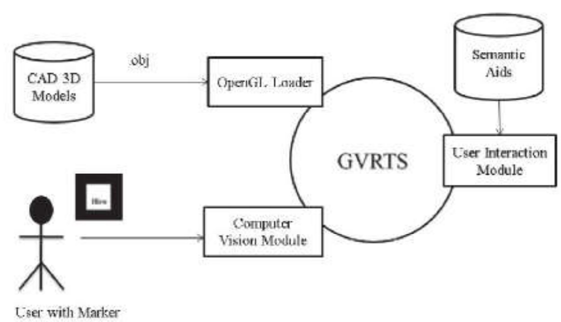


Fig. 3 . Illustration of the main modules of GVRTS

Three Dimensional Models

All the components of the three phase step-down transformer and the entire environment are designed (with high quality) in 3D Studio Max 2009. These models along with\ texture, colour, and material information are then converted to .obj file format and finally exported to OpenGL Loader software.

OpenGl Loader

This module is responsible for conversion of .obj file in to VE along with placement of objects at specific locations.

Computer Vision Module (CVM)

Interaction with GVRTS is based on computer vision system to make the system more realistic and simple along with reduction in cost and complication. It will also ensure easy implementation of the system at various organizations. CVM has three main modules i.e. ARToolKit Markers, ARToolKit Library, and a camera. The ARToolKit Markers pare black and white patterns. A normal video camera is used to capture an input video stream, which is further analysed by an algorithm and compared with patterns of ARToolKit Library. If the pattern is matched its position and orientation is measured by the ARToolKit and sent to the VE.

User Interaction Module (UIM)

The most important prerequisite of any VE is the realistic and simple interaction. UIM controls various operations of the VE including navigation, selection, manipulation, inter-object collision detection, collision detection between object and the virtual hand and other 3D interaction tasks (Fig. 4)

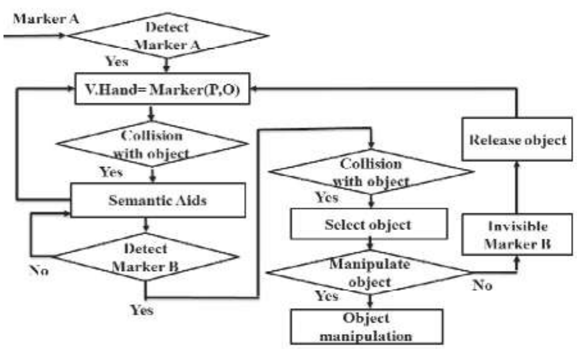


Fig. 4. Flow diagram for navigation, object selection and manipulation using markers

The system allows free 3D navigation in the VE. The user (represented by the virtual hand) can move (navigate) freely in all directions (x, y, and z) in the VR environment. The virtual hand is mapped with the marker Fig. 4, whenever user moves the marker using his hand in the real environment, the virtual hand follows its motion in the VE dynamically in real time. The camera also moves along with the virtual hand in the VE.

Many selection and manipulation tasks are performed in the VE. In this process first the object selection is performed by the virtual hand and then various manipulation operation are performed. The manipulation may be the change of behavior of an object (color change of object, and change in position etc.). Interaction (identification, selection, navigation, and manipulation etc.) in VE is made using ARToolKit markers. Free navigation and object identification is carried out using free movement and visibility of a single marker in front of camera Fig. 5(a). For the selection of an object the collision of the virtual hand with object and the visibility of second marker is required Fig. 5(b). Making the second marker invisible to the camera, simply release that object. The user can dynamically perform these operations (navigation, selection, manipulation (rotation, movement), and release) on different objects in the VEs.

Guidance in GVRTS

For assistance of students in the assembly task, GVRTS guidance system provides two types of cognitive aids. These aids are direct aids and semantic aids.

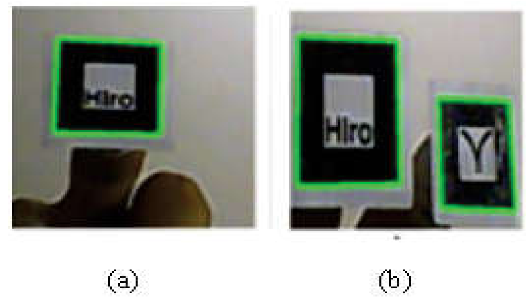


Fig. 5. Interaction via ARToolKit markers (a) Single marker (b) Two markers both visible

1) Direct Aids

The explicit information/aids such as color change, arrow above an object, haptic force towards target/object, lighting or shadow above a position etc., provided by the system to assist trainee in performing the task. Direct aids provide direct and straightforward clues for the trainee which results in error free task operations. They are easy to use and follow/interpret instructions during task operation . GVRTS system offers directs aids in the following forms:

- Object color change
- Guiding arrow using color change or blinking
- Guiding arrow using movement (up-down)
- Appearance of line bar (color) below the selected object

As the user (virtual hand) navigates inside the VE, the system changes the color of the object to be selected. In this way the system leads the user to select only the specified object in the assembly task. As the user selects (picks) an object, the system displays a blinking arrow just above the specified target location. The arrow moves up-down while frequently changes color to red and yellow which guides the user towards the final position of the selected object Fig. 6. To help the user to place the selected object at precise position, a vertical color line bar below that object is used Fig. 6.

1) Semantic Aids

Direct aids help trainee to perform an action easily and accurately, but there is no exploration i.e. they give no information/knowledge related to objects (object name, type, and function) or task (sequence of steps involved in assembly task, relationship between parts etc.). Semantic aids are short meaningful (information rich) cognitive aids offered by the system to the user.

These aids are used to improve students learning (exploration) related to objects and assembly task in the VE. These aids are provided in the following two forms i.e. visual semantic aids and verbal/audio semantic aids.

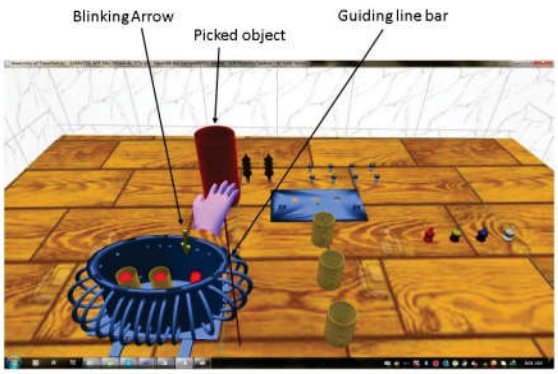


Fig. 6. Transformer assembly realization through various direct aids

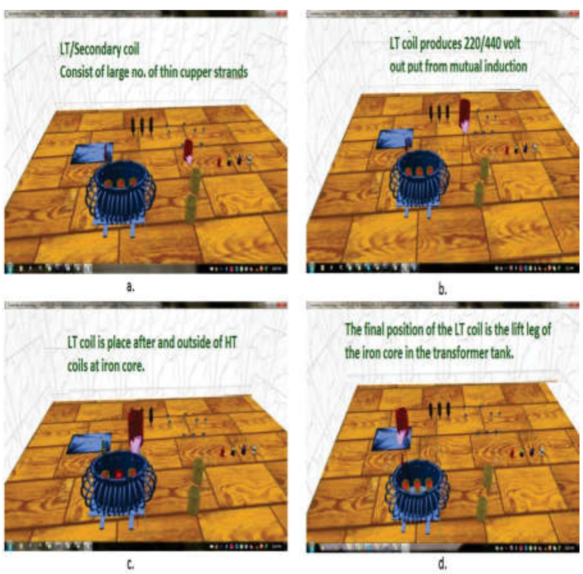


Fig. 7. Provision of semantic aids for selected object (a) name plus structure (b) Function (c) Sequence of placement (d) Target (destination) position.

a. Visual semantic aids

The system provides semantic aids visually (textually). These aids (information) are provided to user step by step to enhance their learning gradually during the assembly task. As the user picks the object, the system provides semantic aids related to object's name and structure Fig.7a, which improve students learning related to parts identification.

In the next step, the system provides information concerning the object's function Fig. 7b. These information are used to increase students' learning regarding working and function of transformer objects. After that semantic aids concerning the relationship between objects in the assembly task are delivered by the system Fig. 7c. These aids increase students' learning related to different steps in the assembly task as shown in Fig. 7c. Finally information related to object's target location are delivered to students. This will improve the knowledge concerning objects' final position in the assembly Fig. 7d.

b. Verbal semantic aids

In this type of semantic aids, the system provides information (semantic aids) related to each step (as discussed in the previous subsection) to users verbally or in audio form.

IV. Experiments And Evaluation

We performed experimental (objective and subjective) evaluation to examine the effect of semantic multi-modal and direct aids in GVRTS on students learning, task performance and knowledge transfer to real environment.

Fig. 8. A user performing the assembly task experiment on GVRTS.

Protocol and task

To evaluate the GVRTS we used 80 participant in the experimental setup. We selected male students from different polytechnic institutions. They were students of 3rd year and they had ages from 19 to 22 years. The subject of three phase step-down transformer was contained within their course. Four groups (i.e. G1, G2, G3, and G4) were made. Each group contained 20 students. Students of G1 used GVRTS with direct aids Fig. 6. G2 used the system (GVRTS) with direct plus visual semantic aids as shown in Fig. 7a-d. Direct plus audio semantic aid are used with GVRTS for G3 while that of G4 used direct aids with combined audio visual semantic aids. All the students were briefly demonstrated about the usage of the system. They were also educated about how to perform different operations in the VE i.e. how to navigate, select, and manipulate different objects in the GVRTS. After that each participant performed the assembly task of transformer in the GVRTS using their specified aids Fig. 8. After performing the task each student filled a questionnaire. After completion all the questionnaires were collected for analyses.

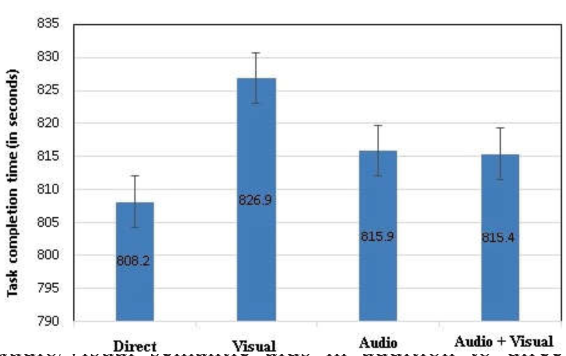
In the second phase all the students (G1, G2, G3, and G4) had to perform the assembly operation of a real world transformer in a workshop.

V. Result Analysis

This section presents objective (task execution time) and subjective (questionnaire) analysis of all the four groups (G1, G2, G3, and G4). After that, analysis of transfer of knowledge in real environment is carried out.

Objective analysis (Task execution time)

In the objective analysis, the execution time of G1 is 802.2 seconds (STD=9.95), whereas that of G2 is 826.9 seconds (STD=12.03), for G3 it is 815.9 seconds (STD=10.82), and for G4 is 815.4 seconds (STD=9.25), as shown in figure Fig. 9. The direct aids which were used by G1 achieved good performance (short task execution time) among all groups. As direct aids involve little cognitive processing so students completed the task in less time. The task execution time of G2 was greater than G3 and G4. The reason for the high task completion time is the loss of control in performing the task as the users were looking and reading the textual information during task operation. While completion time for G3 and G4 is approximately the same. So it means that providing semantic aids in audio and visual plus audio form gives the same good performance results as compared to visual aids only.



guidance aids on students' learning, we used a questionnaire. The questionnaire included three questions. A scale of 1 to 5 was used to answer these questions. Where 1= low and 5 = very high level. The analysis of these answers is given below.

1) Learning in GVRTS

On the basis of the following perspective, evaluation of the students' learning in GVRTS is carried out in real environment.

- Parts identification
- Steps in assembly task
- Function of transformer parts

Following were the questions:

Q1. Up to what extent did you learn about the name of each part of transformer?

Q2. Up to what extent did you learn about the functions of various parts?

Q3. Up to what extent did you learn about the steps involved in the assembly?

To achieve best quality along with realistic view, 3D Studio Max 2009 was used for the development of all parts of the step-down transformer. The question concerned with parts identification, 58% students of G1 voted for the very low level of learning choice, 22% for high, and 20% for higher levels Fig. 10. 40% of G2 students selected high and higher level options, 40% of G3 students opted for the high level and 60% selected the highest level, whereas 30% opted for high level and 70% for highest level in G4. From the above results, we can conclude that groups with semantic aids got more knowledge as compared to group with direct aids in the identification of parts.

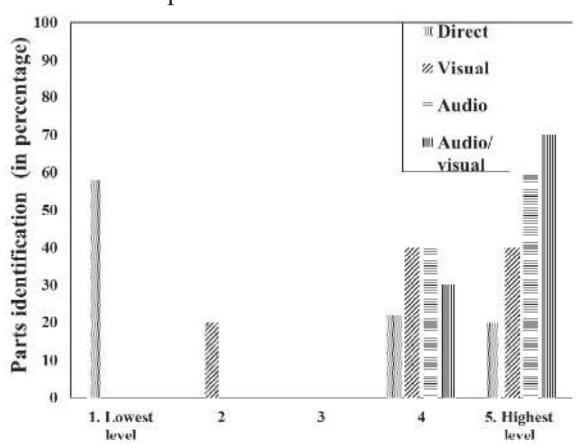


Fig. 10. Identification of transformer parts.

For the question concerned with learning the assembly steps, students of G1 responded with 40% for high level while 30% for nuetral Fig. 11. 50% students of G2 selected the highest and 40% high level learning option. Students of G3 voted 50% to highest and 30% to high level learning option while students of G4 selected 60% to highest level learning while 40% to high level option. The results showd that G1 which used direct aids got little learning as compared to other groups which have nearly the same results. The use of semantic aids in different groups got nearly the same results but combined audio/visual semantic aids used by G4 got comparabaly good results.

Question concerning to function of transformer parts, students of G1 voted 90% to lowest level as shown in figure 12, while G2 students voted 40% to high level and 20% to highest level option. Students of G3 selected 50% to both high and highest level of learning. Similarly students of G4 opted 50% to each of high and highest level option. From the above results we can conclude that students of G1 got lowest level of learning. In learning related to function of transformer parts, G4 is at the topmost position in learning while G3 is on the second position. So it can be concluded from the above results that the using both audio/visual semantic aids were better as compared to single visual, audio, or no semantic aids.

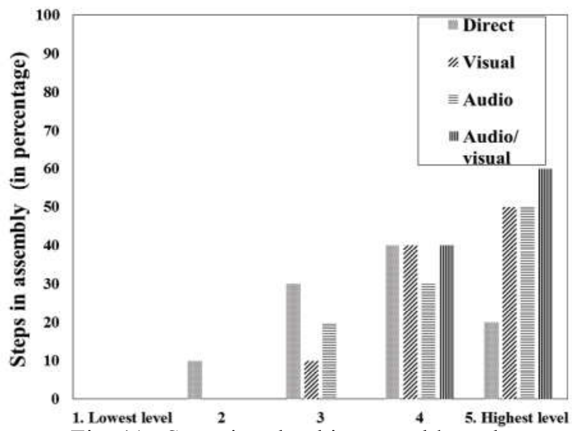


Fig. 11. Steps involved in assembly task

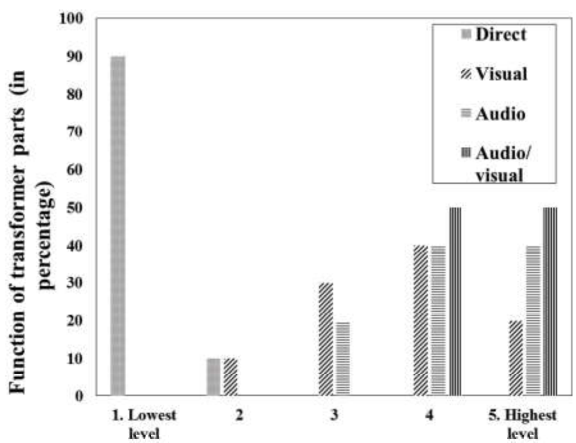


Fig. 12. Learning related to function of transformer parts.

Transfer of knowledge into real situation:

Finally we analysed transfer of knowledge in real world workshop in the final stage of our experimental study. For this purpose we brought all the groups to a physical workshop. The evaluation was done on the basis of the following perspectives:

- Identification of the real world transformer parts
- Function of transformer parts
- Order of steps in the assembly task
- Relationship of transformer parts in the assembly task

Each part of transformer in the GVRTS was designed in 3D Studio Max in order to get best quality and increase realism. Due to the high quality of models and resemblance with real word transformer, they were easily identified by the students. Students of G1 responded correctly to object identification as shown in Fig. 13. While students of G2, G3, and G4 with 81%, 83% and 90% correctly identified the transformer parts. The results shows that the use of semantic aids (combined audio/visual) in GVRTS highly improved students' learning related to parts identification. As there was no great difference among students trained with audio semantic aids and visual semantic aids. There is no source for knowledge improvement using direct aids, the 43% of correct responses came due to physical appearance of some transformer parts in real world such as transformer tank, nut bolts, and bushes etc.

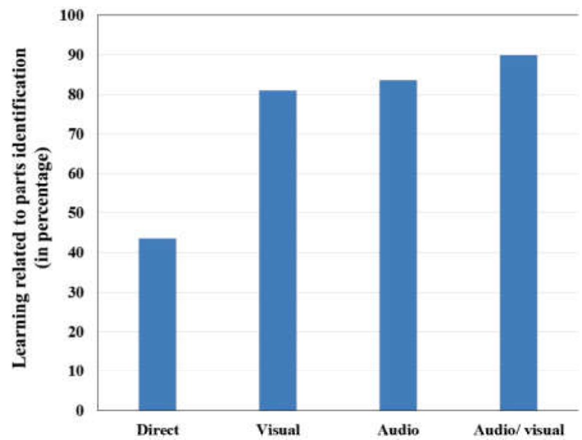


Fig. 13. Learnig associated with parts identification.

Learning associated with the steps involved in the assembly task, the response from studetns of G1 was 38.5%, whereas 78.5% of G2, 82.2% of G3, and 96.1% of G4 Fig. 14. So it means that there is a low level learnig of students who used the system with only direct aids as compared to those who used semantic plus direct aids. While the combined audio/visual semantic aids have better resluts as compared to only visual or audio semantic aids.

For the learning concerned with transformer parts' final position, the correct response of G1, G2, G3 and G4 was 46.7%, 83.5%, 82.3%, and 89.6% respectively Fig. 15. The above results revealed that the use of combined (audio/visual) semantic aids outperformed as compared to others.

VI. Conclusion And FUture Work

In this paper we proposed semantic aids with direct

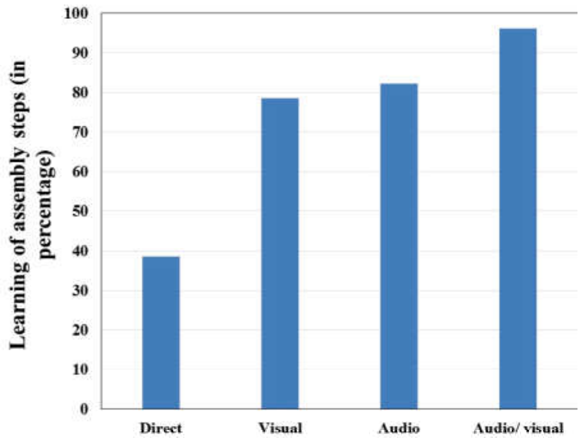


Fig. 14. Learning related to steps in assembly task.

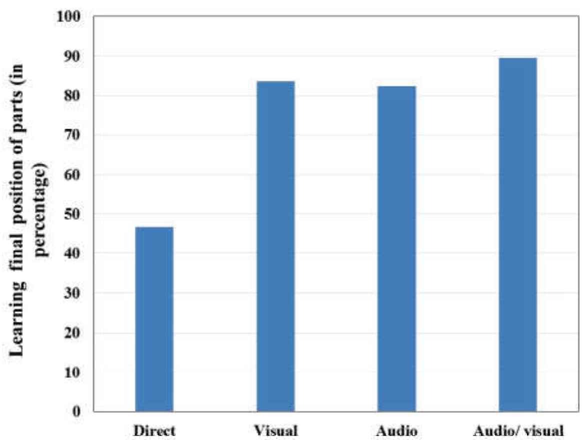


Fig. 15. Learning associated with transformer parts final position.

aids in order to get the benefits (high performance) of direct aids while to decrease its low learning effects. For the experimental study we used Guided Virtual Reality Training System (GVRTS), a desktop based VE. Fiducial markers were used for interaction with the system. A comparison based on task performance, resulted in less performance drop in case of the use of semantic (audio, visual, and combined) with direct aids as compared to simple direct aids. Experimental results also revealed that semantic aids considerably improved learning and knowledge transfer to the real world.

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