The Impact of Active Versus Passive Use of 3D Technology: A Study of Dental Students at Wuhan University, China

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Abstract: A variety of computer-based 3D applications are becoming regular tools for dental students for self-learning. This study investigated the learning effectiveness of junior dental students in passively versus actively controlling the 3D virtual scenes of implant dentistry. Participants were randomized into three groups and were exposed to three designs of educational materials: traditional 2D webpages (2D); active-controlling 3D webpages (A3); and passive-controlling 3D webpages (P3). After reviewing the webpages, the participants were asked to complete a posttest to assess the relative quality of information acquisition. Their responses were compared and analyzed. The results indicated that the P3 group received the highest score of 26.4±3.1 on the posttest, significantly better than the A3 group, which had the worst performance with a score of 20.3±4.0. The 2D group received a score of 24.2±4.6. There was a significant correlation between the scores on a mental rotations test and the subjects’ performance on the posttest (p<0.001). A serious disadvantage of active control was indicated for individuals with low spatial ability. In 3D virtual reality assisted self-learning, passive control produces higher learning effects compared to active control. Too much active control may generate significantly negative impacts on students, especially for individuals with low spatial ability.

Keywords: dental implant, educational technology, computer-assisted instruction, virtual reality, dental education, China

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Computers and the Internet are becoming regular tools for dental students for purposes of education and research. Internet-based learning encourages the students to engage actively in education partly due to the convenience of information retrieval and the variety of applications available online. As the worldwide usage of the Internet dramatically increased over the last ten years, dental students have shown growing interest in the Internet and other e-tools for assisting their self-education.

On the other hand, some researchers in certain fields held conservative views towards using the Internet and computer applications as part of an effective educational strategy and indicated no positive or negative impact from e-learning. However, we assume it is important to identify where these negative influences originate. It is critical to distinguish between the computer technology and the design of those e-learning resources. The former allows advances in information technology to change the ways of information dissemination and acquisition; the latter incorporates cognitive psychology and educational design. Inappropriate design of e-learning materials would undermine the potential benefits of these innovative media.

A dental implant is an artificial tooth root used in dentistry to support prosthetic restorations that resemble a tooth or a group of teeth, including crowns, implant-supported bridges, or dentures. Dental implant therapy is an ideal option for people in good general oral health who have lost a tooth or a few teeth due to periodontal disease, an injury, or some other reasons. However, learning implant dentistry is much more difficult and requires greater efforts and a longer period of training for students or clinicians compared to traditional prosthetic dentistry. Presumably because of this, dental implant education was not or was very little included in the predoctoral curriculum in China ten years ago. Although recent data indicated that most dental schools had introduced implant dentistry in lecture series, the abstruse theories, complicated surgical procedures
within implant dentistry, and absence of systematic preclinical training in college curricula all made it one of the toughest courses in dental education.

Currently, an effort has started to look into the usage of 3D materials to assist the education of implant dentistry. Although very limited concrete data have indicated its potential value, positive attitudes of the reviewers subjectively suggested the 3D materials could be an interesting and effective tool, not only for patients but also for education, and thus anticipated its future popularity and wide application.

Our series of studies were designed to develop the optimal method to benefit dental students by utilizing the Internet-based 3D virtual reality (VR) as an educational aid. In 2007, we found that 3D materials, incorporated into regular course settings, could produce positive effects in aiding preclinical training of junior dental students. In 2009, we developed a prototype of web-based 3D educational system. Both of our studies again suggested that the 3D VR technology could be part of a promising strategy to educate dental students properly under certain circumstances. However, it remains unclear as to the optimal design of the 3D VR and its integration into traditional 2D webpages.

In addition, one of the important variables in e-learning instructional design, especially in the 3D VR, relates to the degree of learner control over study materials. The assumption was that dental students would gain benefits when given more active control over the 3D VR manipulation. Nevertheless, our previous unofficial observation suggested that passive learning might be a better way for the majority of students compared with active control over the 3D VR. The existing literature suggested that contrary views on this issue were held by different investigators. Willjelm encouraged active learning in medical imaging. Hahm et al. supported the theory that an individual’s active navigation could play an important role in spatial cognition in VR environments. However, others found evidence suggesting that increased learner-controlled courses may not be effective for individuals with little background knowledge or low metacognitive capabilities. It is possible that different environments, study design, test subjects, and key variables could have contributed to this diversity in the conclusions. Although Keener et al.’s studies in cognition in 3D environment might give some reasonable explanations for this confusion, the study in our specific environment was designed to seek the answers and possible reasoning within.

The aim of this study was to compare the use of active versus passive approaches in using the 3D virtual scenes in dental implant cases. It might provide important guidelines on designing control mechanisms for educational 3D software to make it more effective, easy, and fun to use.

**Methods**

The study was undertaken in the School and Hospital of Stomatology, Wuhan University, China. Approval for the study was granted by the General Dental Hospital Review Board, Wuhan University for Protecting Human Subjects. All information used in this study and data analysis was self-reported by participants during the study. Data from the study were anonymous, and all information remained confidential.

Students who just entered or had finished their first year of the dental course were invited to participate in this study. These two grades of students had not been given lectures or training on dental implants before this study. Interested volunteers were invited to a classroom equipped with regular computers. All volunteers were informed about the purpose and content of the study, and a written consent was obtained from each participant before the investigation. Upon completion of the study, participants received a small gift and extra credits in appreciation for their time and contribution.

Demographic information was collected on each participant including gender, average performance on fundamental courses, and experience with computers and the Internet and 3D applications. All participants undertook a standardized test of spatial ability (mental rotations test, MRT). After the completion of the MRT, participants were randomized into three groups and were allocated three different types of educational webpages: the traditional 2D webpages (2D), the active-controlled 3D webpages (A3), and the passive-controlled 3D webpages (P3). Similar information on dental implant restoration, in different styles, was present on the three types of webpages. The 2D webpages contained only traditional multimedia such as texts, 2D pictures, photos, and regular movies. The A3 webpages, in addition to 2D webpage materials, contained windows where 3D interactive virtual reality was available for interaction. The P3 webpages, similar to A3, also had 3D interactive windows. However, these 3D windows would not allow the users to interact with
them freely. Instead, some buttons were designed to activate pre-set key views of the 3D scenes, either in a static or animated manner. The passive interaction allowed the users to access the key views of the 3D scenes by simply clicking buttons, but it deprived them of the ability to rotate, zoom, or pan the 3D scenes freely.

Before the webpage-based self-learning exercises, A3 and P3 members received a manual on operating the 3D system, and a further orientation was designed specifically for all A3 members. All participants were asked to complete the self-learning process with no time constraint, no inquiry with professionals, and minimum assistance on technical issues. All webpages presented only general knowledge regarding implant dentistry.

After completing the self-learning, the participants took a forty-item posttest designed by three dental implant experts and J. Hu. Detailed design of the test is shown in Table 1. Of the forty questions, thirty addressed issues closely relating to anatomy or morphology with answers that could be found in the graphic information presented on the given webpages, either in 2D or 3D format. Participants were asked to give an assessment of their satisfaction regarding the tested webpages (ASW) as well as a self-evaluation on their acquisition of information after interaction with the webpages (SAI), both on a scale from 0 to 10.

An assistant was assigned during the study to be responsible for providing and setting up all webpages for participants, administering the MRT and the posttest, and sending all the results back to the authors. The assistant also helped A3 participants to restart the manipulation or reset the view if they were completely lost in the 3D coordinate and were unable to continue. This assistance was minimal and solely for the purpose of allowing students to continue the test. They were given no assistance with performing any specific manipulation or obtaining any key views.

In producing the 3D materials, raw 3D models and virtual scenes were generated and edited in 3Dsmax 2009 (Autodesk, USA), with certain animations preset in the 3D scenes. Then the 3D scenes were exported and reedited in a 3D webpage maker, Webmax 2.0 (Suntoward, Shanghai, China). Using Webmax enabled the 3D scenes to be re-edited for subsequent proper display in webpages. Meanwhile, it was possible to activate preset animations and programmed interactivity. Subsequently, the 3D scenes were exported as independent 3D webpages or merged into traditional 2D.

The 3D VR windows allow the users to view and interact with the 3D scene. Basically, the 3D scenes can rotate, pan, and zoom in/out although more sophisticated manipulations can be performed. For example, the users can make the selected/unselected parts invisible or transparent, create an imaginary cross-section anywhere, or control the programmed animation by right-click menu. In the A3 materials, the users perform all operation by specific manipulation, but in P3 the users only click a preset icon to initiate a key view or an animation.

All types of webpages were designed with the collaboration of all authors together with a senior dental implant specialist and two computer engineers. In designing the webpages, the experts combined the contents of a current textbook of implant dentistry in China and some multimedia advertisements produced by implant manufacturers such as Nobel Biocare and Straumann, focusing on the surgical and prosthetic procedures of restoring a single missing tooth by implant prosthesis.

Before statistical analysis, the characteristics (mean, standard deviation, distribution) of each variable were assessed. This greatly helped us in choosing the most appropriate statistical approach in our downstream analysis. The potential bias during the randomization process was assessed also for the three randomized groups. For variables where the normality assumption was not met, the corresponding non-parametric test was conducted in addition to its parametric counterpart. For example, the Wilcoxon rank-sum test or two-sample t-tests were used for checking differences between two groups, while Kruskal-Wallis and ANOVA tests were used for checking differences among three groups. When assessing the covariate effect, univariate and multiple linear regression analyses were applied to assess the

<table>
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<th>Table 1. Design of forty-item posttest</th>
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<td>Dental hygiene required for caring for implants</td>
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<td>Others</td>
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effects of covariate alone and in conjunction with other variables. Bonferroni procedures were applied for the correction of results from multiple statistical testing.

**Results**

Of the ninety-seven participants, two failed to complete the study: one for personal reasons and the other reported nausea when exposed to the 3D VR environment. Thus, we had ninety-five valid responses for the final analysis. No differences in demographic or other variables (gender, performance on fundamental dental courses, and experience with computers and Internet and 3D applications) and MRT were detected in the three groups, indicating that the grouping process for participants was completely random. All manipulations in the A3 group progressed smoothly. Only four participants requested assistance when unable to continue with the active operation. In these cases, the assistant set the views back to normal or default mode, from whence the users could recommence their navigation.

First, we compared the posttest scores of the 2D group against the combined 3D groups (A3+P3) (Figure 1) and found no significant differences between the two groups (p=0.4018 in the t-test). This result appeared to indicate that the 3D materials had no advantages over the 2D webpages. However, after we further separated the two 3D groups and tested for any difference for posttest scores among the three groups (comparing 2D vs. A3 vs. P3), a significant trend (P3>2D>A3, p<0.001 in both ANOVA and regression test) appeared among these three groups (Figure 2). The P3 group received the highest score of 26.4±3.1, whereas the A3 group performed the worst with a score of 20.3±4.0. Scores for the 2D group were intermediate (24.2±4.6). To validate this, we carried out the pairwise t-test in subsequent analyses, and highly significant differences were found between A3 vs. P3 and A3 vs. 2D (p<0.001) (Table 2). There was a marginally significant p-value observed when comparing the 2D vs. P3 group (p=0.08 in pairwise t-test). The significant results remained unchanged even after Bonferroni corrections (using a more stringent p-value significance cutoff: 0.05/3) for multiple testing. In general, passive control had significantly more advantages than the active control in the 3D groups. The 3D materials with passive controlling design, even though not statistically superior to 2D materials in this study, achieved the highest score compared to the other two groups.

We further studied how MRT affected posttest performances across the groups (Figure 3). Higher MRT scores were associated with better posttest performances in all three groups (p<0.001). This implies that low spatial ability correlated with poor performance in the posttest. More importantly, we found that this pattern was more predominant in the A3 group, i.e., the same unit dropping of MRT score caused a larger decrease in the posttest score for the A3 group than the other two. This implies a serious disadvantage of using active control by individuals with low spatial ability in a 3D VR environment.

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**Figure 1. Box-and-whisker plot for posttest scores between 2D and 3D (A3 plus P3 groups)**
This possibility was supported in the study, showing that the performance of the A3 individuals with low spatial ability was the worst.

We assumed that demographics would influence the posttest performance of the participants. However, in using univariate and/or multiple linear regression analysis, all the above covariates were insignificant for predicting posttest scores.

The Kruskal-Wallis (non-parametric counterpart of ANOVA) test indicated significant differences on ASW among the three groups \((p=0.026,\) insignificant after Bonferroni correction), although further pair-wise comparisons using Wilcoxon rank-sum test only brought about two marginally significant and one insignificant p-values \((p=0.060 \) for A3 vs. 2D, \(p=0.063 \) for P3 vs. A3, and \(p=1.000 \) for P3 vs. 2D). A similar analysis was conducted for SAI, and again significant differences were detected among the three groups \((p<0.001 \) in Kruskal-Wallis). From the pair-wise comparisons, we found that 2D and A3 did not have significant differences on self-evaluation scores. However, P3 achieved significantly higher scores than the other two groups. Significant results remained the same after Bonferroni correction. Regression analysis indicated that none of the covariates (gender, performance on fundamental dental courses, computer and Internet experiences, and 3D experiences) influenced the ASW and SAI.

**Discussion**

This study provides data regarding the use of 3D materials as self-education resources for dental
Students. Although some previously reported evidence supported that individuals could benefit from visualizations of objects in multiple orientations, our study has shown that too much active control in the 3D world may generate significantly negative impacts, especially for individuals with low spatial ability. In contrast, passive control produces relatively higher learning effects. In designing the 3D application for student self-education, intensive active-control is not recommended, but an adjustable balance between passive and active controlling based on the individual’s spatial ability may be preferable.

It is an ideal goal to help students develop more active participation in e-learning and more active sharing of information or knowledge available through advanced technologies. However, data from this study suggest that extreme active control could lead to failure in a 3D VR environment. In addition, active control over 3D materials may have a severe negative impact on some individuals, especially individuals with low spatial ability. These findings may prevent us from the potential misuse of 3D VR or similar educational materials.

Surprisingly, our study showed that active engagement/control of the media had a negative effect. The study sought an explanation for this, and, fortunately, Keener et al.’s series of studies on cognition in the 3D environment might provide further enlightenment. Keener et al. indicated that spatial ability made an independent contribution to performance on the spatial reasoning task. They stated that active control of computer visualization does not necessarily enhance task performance, whereas seeing the most task-relevant information does and this is true regardless of whether the task-relevant information is obtained actively or passively.

Part of our findings might be explained by the following. First, spatial ability generally affects an individual’s cognition in 3D materials, in a process of either passive or active interactivity, whilst it contributes comparatively less in 2D media than 3D. Second, spatial ability may affect an individual’s basic manipulation in a 3D environment more than the spatial reasoning and cognitive interpretation of 3D visual information. The A3 group might spend too much effort on 3D manipulation, and thus, for individuals with low spatial ability, the 3D materials might prevent them from acquiring the necessary visualization in the first place. Third, of importance to subjects is not whether or how they interact but what they see. The passive controlling pattern provides key visual information to the users in a simple, easy way, whereas subjects in the A3 group might not even access the key visualizations relevant for answering the tests. Fourth, most subjects in A3 were unfamiliar with operating in 3D materials. Although they were provided with an orientation, the novel system plus the new information was likely to distract their attention during their active navigation.

As Wilson and Peruch argued, attention is a crucial factor in spatial learning. The attention of the subject is likely to be taken by the low skill operation that, from another perspective, might have a negative effect on the acquisition and interpretation of the key 3D visualization. Given longer training on manipulating the 3D VR, active controlling may have fewer disadvantages than seen in this study. Verification of this hypothesis could be a topic for future studies.

Our study indicates a more cautious approach to the further use of 3D VR in dental education. This study suggested that the potential advantages of 3D materials are reduced if too much active control is introduced. This viewpoint has inspired us to consider future research on the optimal design of 3D software. A 3D system could initially identify the type of user by such variables as spatial ability, gender, and/or 3D experience and then adapt these to an appropriate pattern of 3D visualization specifically for different types of users based on a balance of passive and active controlling systems. As an example, for users identified as having low spatial ability, with limited experience of 3D applications, the system could switch to a view comprised of traditional 2D plus some 3D animations played automatically. Conversely, for users skilled at computer games, the system could be adapted to using 3D scenes requiring high active control competence.

Finally, it is worth noting that this study had several methodological and theoretical limitations. First, this was an observational study conducted within a specific timeframe and participants selected from a single college. As sampling was not random, it is unclear if the sample was representative of dental students in general. Second, it is possible that the study has an intrinsic systematic bias. For example, IT-literate individuals may be more willing to participate in such a study. This may explain why very few covariates (e.g., experience with computers and the Internet) had a significant effect on outcomes (posttest performance, ASW, and SAI). Third, the results were affected not only by the level of activity/passivity, but also by the specific implementation of different versions of the multimedia. In this study,
if the multimedia had been produced using other technologies or designed by another technical team, the outcomes might have been different.

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