

Anatomy Learning with Virtual Objects

Andrew T. Stull¹, Mary Hegarty², and Richard E. Mayer³

University of California, Santa Barbara

Department of Psychology

Santa Barbara, CA 93106, USA

¹stull@psych.ucsb.edu, ²hegarty@psych.ucsb.edu, ³mayer@psych.ucsb.edu

Introduction

Learning from virtual objects may be more cognitively and perceptually demanding than learning from real objects. Although, it is often assumed that virtual learning objects are as good as their real-world counterparts (Reznick & MacRae, 2008), which explains the growing trend to use interactive, virtual objects, to augment and even replace real-world experiences in classrooms and workplaces (Bearman, 2003).

Basic research on object recognition supports the use of virtual resources in learning showing that actively controlling a virtual object (compared to passive viewing of the object) leads to more efficient recognition of the object after practice (James, Humphrey, & Goodale, 2001). However, research that used these methods to teach anatomy found that low-spatial individuals had particular difficulty manipulating virtual anatomical models and had poorer learning of anatomy compared to high-spatial individuals (Garg, Norman, Eva, Spero, & Sharan, 2002). This is understandable because the manual rotation of an unfamiliar object, including a virtual object, in a goal-directed task is guided by mental rotation, which is known to be spatially demanding (Ruddle & Jones, 2001; Wohlschläger & Wohlschläger, 1998).

Virtual objects burden students with the need to form 3D mental representations from 2D representations on a computer screen. This burden is compounded by the impoverished visual and sensorimotor cues provided by virtual objects (Ware & Franck, 1996) and the interface used for rotating them (Ware & Rose, 1999). This raises the question of whether it may be possible to construct virtual objects in ways that mitigate the challenge of using and learning from them.

The identification of an object's reference frame (i.e., its top/bottom, right/left, front/back orientation) is a common process in theories of both object recognition and mental rotation (Graf, 2006; Marr, 1982). The rotation of virtual objects may be particularly difficult when the object's reference frame is difficult to establish. Establishing the viewed object's reference frame may require identifying the object's main axes (Marr, 1982), identifying distinguishable features of the object, which helps to establish the object's main axes (Corballis, 1988), or both (Humphreys & Riddoch, 1984, 2006). The reference frame may be challenging to determine and maintain, when the orientation of a viewed object is such that the major axes are not discernable, or distinguishable features of the object are occluded. Further, even if the reference frame is correctly established at first view, it may be difficult to maintain as the object is rotated. Under challenging circumstances, viewers might be aided by helping them visualize the viewed object's main axes, recognize distinguishable features, or both.

In this study orientation references—visible lines overlapping the object's major axes—were examined for how they help learners manipulate virtual objects (e.g., an on-screen representation of a bone) during anatomy learning and consequently help learners develop useful mental representations of the anatomical object. Examples of an object with and without orientation references are shown in Figure 1. It is proposed that orientation references will mitigate the disorientation effects that people experience when manipulating virtual objects by reducing extraneous cognitive processing (Mayer, 2009). Lowering the effort involved in object manipulation, in turn, should allow for more cognitive effort to be invested in gaining visual and spatial knowledge of the object.

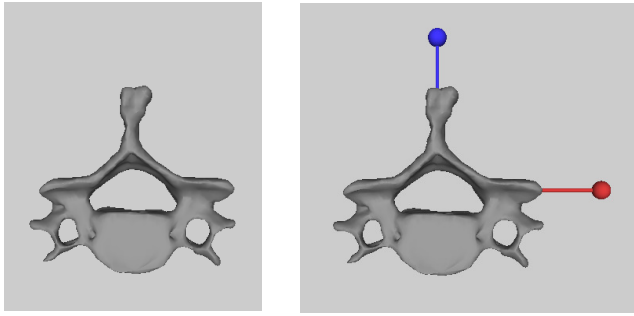


Figure 1. Two versions of the bone model.

To investigate learning using virtual objects, a task was studied in which students learned important structural features of a complex, three-dimensional anatomical object. The virtual lesson was intended to simulate a common teaching practice used in anatomy classes to promote learning through exploration and manipulation of anatomical objects. Both visual knowledge (feature identification) and spatial knowledge (spatial relationships between features) are required if learners are to form a useful mental representation of a complex anatomical object. In the learning phase (*virtual object rotation trials*) people had to rotate a virtual model of a bone (a human vertebra) using a handheld device to match a specific target orientation and note the appearance and location of a target feature. In the course of rotating the virtual bone between target orientations, students were expected to gain visual knowledge of the bone's features and spatial knowledge of the relationships between features. In the knowledge assessment phase, participants were tested on their ability to identify important anatomical features from various orientations of the bone, which happened after the virtual object rotation trials. Accuracy, speed, and efficiency of the virtual object rotations were measured during these trials.

This research makes a theoretical contribution to our understanding of learning of complex objects and an applied contribution through improvements in the design and delivery of virtual learning resources.

Results and Discussion

In three experiments, changes in virtual object rotation performance (i.e., the learning phase) and feature knowledge (i.e., the assessment phase) were compared when participants learned from virtual objects with or without orientation references. In all three experiments, speed, accuracy, and directness of rotation was measured as participants performed a virtual object rotation task in which they attempted to match the orientation of a virtual object to a target orientation, while also noting specific anatomical features of the object. These three dependent measures quantify the success (accuracy in degrees), the effort (response time in seconds), and the efficiency (directness in degree-seconds, i.e., the area under the accuracy-by-time curve) of rotating the virtual object.

Acquired feature knowledge was assessed by a task in which participants had to later identify anatomical features from diverse orientations of the bone model.

Experiment 1

In Experiment 1, (Stull, Hegarty, & Mayer, 2009) the orientation reference hypothesis, which states that providing a reference to the orientation of an object will facilitate rotation and learning performance, was tested for challenging conditions with large rotations around noncanonical axes. First, it was predicted that providing orientation references would lead to more accurate, faster, and more direct rotation of a virtual object to match a target orientation (rotation prediction). Second, it was predicted that orientation references would help participants learn the anatomy (learning prediction). Of particular interest was whether these predictions hold for low-spatial learners as well as high-spatial learners.

The virtual object rotation trials in this experiment were designed to be difficult in that they involved rotations around different noncanonical axes (i.e. not orthogonal to the environment or main axes of the bone) and relatively large angles of rotation ($M = 130.9^\circ$, $SD = 34.0$).

The results supported the prediction that participants rotate a virtual object significantly more accurately, faster, and more directly when given orientation references than when not given orientation references. On average, performance of the orientation reference group was 10.8° more accurate, 2.7 seconds faster, and 514.8 degree-seconds more direct than the control group when manually rotating the virtual object to match a target orientation.

Further, the results showed that virtual object rotation performance is related to spatial ability. Participants with higher spatial ability rotated a virtual object more accurately, faster, and more directly than participants with lower spatial ability.

Finally, the results supported the second prediction in that orientation references helped participants learn the anatomy of the bone. Importantly, this difference in learning due to orientation references was greatest for low-spatial participants. Overall, lower spatial ability participants in the orientation reference group correctly identified more features than those in the control group.

Experiment 2

When the axis of rotation is not aligned with the object, the observer, or the environment, objects are more difficult to recognize (Lawson & Humphreys, 1998) and object rotations are generally more difficult to imagine (Pani, 1993; Shiffrar & Shepard, 1991). Mental rotation is also more difficult for larger angles (Shepard & Metzler, 1971). Because of the importance of mental rotation in performing manual rotation tasks (Ruddle & Jones, 2001; Wohlschläger & Wohlschläger, 1998), performance on the virtual object rotation task should be highly influenced by the axis and angle of rotation.

Experiment 2 (Stull et al., 2009) sought to examine how effects of orientation references are moderated by the axis and angle of rotation. The orientation reference hypothesis was tested for basic and challenging conditions with small and large rotations around canonical and noncanonical axes. It was predicted that orientation references would facilitate performance improvements more when the angle of rotation was large and the rotations were around noncanonical axes.

The results supported the prediction that orientation references facilitate virtual object rotation. Participants using orientation references were 31.08° more accurate and 383.67 degree-seconds more direct than the control group when they rotated a virtual object. In contrast to Experiment 1, participants in the orientation reference group were not faster than participants in the control group.

The lack of an orientation reference effect for response time is possibly due to the less challenging nature of the orientations used in Experiment 2.

Participants with higher spatial ability were significantly more accurate (4.77°) than lower spatial ability participants and 203.95 degree-seconds more direct, but there was no significant difference in speed of virtual object rotation performance between higher and lower spatial ability participants

Large-angle rotations were significantly more challenging than small-angle rotations and rotations around noncanonical axes were significantly more challenging than rotations around canonical axes. For example, when the object was rotated around the noncanonical axis participants were 12.91° less accurate, 421.57 degree-seconds less direct, and 3.66 seconds slower than when the object was rotated around canonical axes. In addition, participants were 10.61° less accurate, 575.37 degree-seconds less direct and 2.43 seconds slower when they performed large angle rotations than small angle rotations. The results also showed that the challenge of large angles and noncanonical axes was diminished for the orientation reference group, replicating Experiment 1. For example, the difference in accuracy for rotations around noncanonical versus canonical axes was 21.8° in the control group but 4.0° in the orientation reference group. Similarly, the difference in accuracy for large angle versus small angle rotations was 20.0° in the control group but 1.2° in the orientation reference group. The benefit of orientation references was mirrored in directness measures. The difference in directness for rotations around noncanonical versus canonical axes was 562.89 degree-seconds in the control group but 280.25 degree-seconds in the orientation reference group.

The orientation reference group did not identify more features correctly in the posttest than the control group and lower spatial ability participants did not significantly differ from higher spatial ability participants.

Although posttest performance was generally good (average of 75% correct in Experiment 1 and 69% correct in Experiment 2) a post-hoc analysis revealed a significant difference between posttest feature identification in the two

experiments. In Experiment 1, the orientations used for the rotation phase were equally challenging to the orientations used in the posttest phase (i.e., large angle rotations around unique noncanonical axes). In Experiment 2, participants performed simpler rotation trials (i.e., rotations in 30° increments around 3 canonical axes and one noncanonical axis) and were tested with more challenging orientations in the posttest, the same orientations used in Experiment 1. The observed decrease in learning performance between Experiments 1 (75% correct) and 2 (69% correct) could have resulted from practicing with simple orientations that did not prepare the participants for testing with more challenging orientations.

Supplemental Analyses

Observations over the course of Experiments 1 and 2 suggest that some of the confusion experienced by learners and, hence, the advantage provided by the orientation reference technique, may be due to the shape of the virtual object. Participants were frequently observed to make large errors in the accuracy of their match of the target orientations. As illustrated in Figure 2, these large errors can be explained after considering how similar two views appear when they differ by a large rotation angle. The two images illustrated in Figure 2 are of the same object, but they differ from each other by a rotation of about 180° around the object's vertical axis. Large errors most likely arise because of confusion due to the symmetry of the object. Therefore, orientation references may help by disambiguating the symmetry of the object.

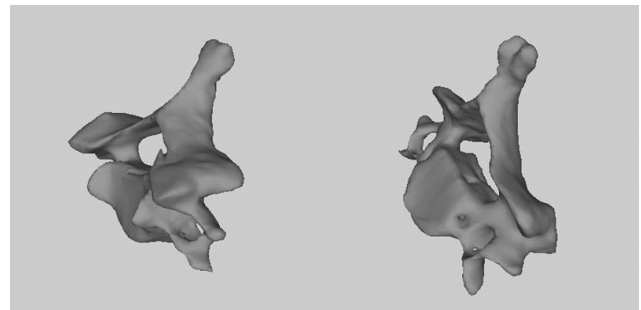


Figure 2. Two orientations that differ by a rotation of approximately 180° around the object's vertical axis.

Figure 3 illustrates the composite target matching error (vertical axis) for each of 40 trials (horizontal axis) for all participants in the control group (left) and orientation reference group (right) in Experiment 1. Notice that for the control condition, numerous errors occurred near the 180° extreme. Participants in Experiment 2 exhibited a similar pattern.

In summary, the results of the supplemental analysis suggest that other than making the object's main axes salient or providing distinguishable features, a third possible reason for the effectiveness of orientation references may be that they disambiguate the symmetry of the object. Post hoc analysis revealed that many participants confused the target orientation with an

orientation that differed from the target by a rotation close to 180°. Such an orientation presents a false but superficially similar view to that of the target. The shape of the stimuli used in this study may have contributed to this effect. By rotating the object 180° around the object's axis of symmetry, the object presents a near perfect match of large-scale features (outline and location of major structure), but not small-scale features (shading, texture, and minor structures) between rotationally symmetrical orientations. Once deceived by the large-scale visual cues to be drawn toward a symmetry error, the learner may become trapped unless they reach the insight that they have confused the orientation of the object.

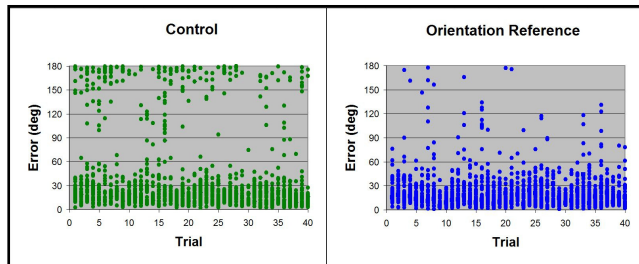


Figure 3. The control group had a bimodal distribution of errors.

Experiment 3

In Experiment 3, (Stull, 2009) three hypotheses were compared as possible explanations for the orientation reference effect. The theoretical foundation for the orientation reference effect centers on the hypothesized need of the observer to establish and maintain the viewed object's frame of reference in order to facilitate object recognition. The stimuli for this experiment are illustrated in Figure 4.

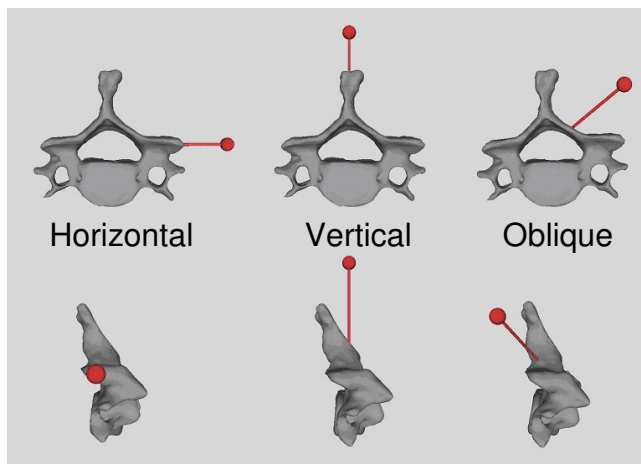


Figure 4. Orientation reference varied by position.

According to the salient axis hypothesis, symmetry errors (120° to 180°) should be less common when an orientation reference is aligned with either the object's vertical or horizontal canonical axis than in a control condition with no orientation reference and no difference between a

control condition and when an orientation reference is oblique to all of the object's canonical axes.

According to the salient feature hypothesis, symmetry errors should be less common when an orientation reference is aligned with the vertical, horizontal, or oblique axis than in a control condition with no orientation reference.

According to the symmetry disambiguation hypothesis, symmetry errors should be less common when an orientation reference is aligned with the horizontal canonical axis or the oblique axis than for a control condition with no orientation reference. Further, the incidence of symmetry errors should be no different between a vertical axis condition and a control condition, because the vertical orientation reference does not affect the symmetry of the object.

The results supported the symmetry disambiguation hypothesis. Participants in the horizontal and oblique groups significantly outperformed the control group with fewer symmetry errors. In addition, the vertical group did not differ significantly from the control group in the number of symmetry errors. This pattern was matched by the data for the accuracy of virtual object rotations. In contrast, the results for directness, response time, and feature identification are more equivocal for the different conditions.

Sekuler and Swimmer (2000) showed that participants used the object's axis of symmetry and axis of elongation to establish its primary axis in object recognition. Importantly, there is limited research investigating how an observer determines an object's secondary axes. It is confusion over this secondary axis that appears to contribute to the incidence of symmetry errors. The placement of the orientation reference to the side of the object helps to make the secondary axis salient.

Conclusion

The goals of this study were to investigate a technique to mitigate user disorientation and promote learning when using virtual objects and to investigate the factors that contribute to disorientation when working with objects in virtual reality. In Experiments 1, 2, and 3, the effects of orientation references were examined when people learned anatomy by manually rotating a virtual 3D anatomical bone and paying attention to labeled features of that bone.

Are Orientation References Helpful?

Orientation references were shown to help learners rotate virtual objects more accurately and directly in Experiments 1 and 2. When only a single orientation reference was provided, as in Experiment 3, accuracy of virtual object rotation was shown to be significantly better with horizontal or oblique orientation reference but not a vertical reference.

Learning performance was also shown to be positively affected by orientation references. In the challenging

conditions of Experiment 1, orientation references reduced the differences in anatomical learning between higher and lower spatial ability participants. In particular, low-spatial individuals learned the anatomy better with orientation references than without orientation references. Otherwise, learning was equivalent with and without orientation references in Experiments 2 and 3. The learning performance was not compared between low- and high-spatial learners in Experiment 3, which investigated the use of a single orientation reference because of small and imbalanced sample sizes.

The orientation reference technique represents one possible practice for helping students learn with virtual reality. Where active instructional feedback is available, improvements in learning should be expected over the passive technique explored in this study. What the orientation reference technique provides is low-cost support when learners do not have a dedicated tutor.

For Whom Are Orientation References Helpful?

Individual differences in spatial ability may contribute to disorientation when students work with virtual objects. Learners tended to confuse the orientation of the virtual object and commit symmetry errors. Orientation references are helpful because they give very basic but highly salient visual cues to make the secondary axis of the object salient.

Individuals with lower spatial ability had a poorer performance when rotating the virtual object compared to participants with higher spatial ability. This result is consistent with previous findings that low-spatial individuals have difficulty manipulating and using 3D virtual models (Cohen & Hegarty, 2007). It might be assumed that orientation references are primarily beneficial for low-spatial individuals; in fact, orientation references were helpful for both high- and low-spatial individuals. This result demonstrates that learners of all levels of spatial ability can be challenged by 3D virtual models.

Spatial ability was a contributing factor to anatomical learning, consistent with previous research (Rochford, 1985). In Experiment 1, high-spatial individuals in the control condition outperformed low-spatial individuals in that condition. Interestingly, this difference was reduced in the orientation reference condition, suggesting that providing these aids alleviated difficulties faced by low-spatial individual in learning anatomy.

When Are Orientation References Helpful?

The results of this study suggest that orientation references are helpful when the learner must mentally or manually rotate a virtual object over a large angle, around a noncanonical axis of rotation, or both. In addition, orientation references are helpful when the shape of the virtual object allows for ambiguous orientations. Finally, orientation references are helpful when low ability challenges the learner to extract, encode, or integrate spatial information from the object.

It is interesting that manual rotation of virtual objects is affected by axis and angle of rotation, which are also performance challenges associated with mental rotation (Pani, 1993; Parsons, 1995; Shepard & Metzler, 1971; Shiffrar & Shepard, 1991). This supports the view that mental rotation is a component of manual rotation (Ruddle & Jones, 2001; Wohlschläger & Wohlschläger, 1998). These common challenges to mental and manual rotation tasks suggest that individual differences in spatial ability may contribute to the ease with which some participants use hand-held interfaces to work with virtual objects.

How Are Orientation References Helpful?

Given the positive effects of orientation references in this study, it is important to consider the mechanisms by which they confer benefit. The orientation reference hypothesis was based on the importance of establishing an object's reference frame during recognition (Corballis, 1988; Graf, 2006; 2006; Humphreys & Riddoch, 1984, 2006; Marr, 1982). This aspect of object recognition is relevant to both virtual object rotation and recognizing features of that object from different orientations. The results of this study suggest that orientation references are helpful because they disambiguate the symmetry of the object and help the user establish but also maintain the object's secondary axis as it is rotated. Although bilateral symmetry and elongation of an object have been shown to promote the establishment of a primary axis, the rotational symmetry of the object challenges the learner to establish and maintain the object's secondary axis.

Implications for the Design of Interactive Visualizations

The results of this study suggest that virtual learning resources, under some conditions, may increase rather than diminish the burden imposed on some learners in spatially demanding professions. Poorly designed virtual resources can impose an unnecessary yet preventable disadvantage for individuals who, if given adequate aids, may develop into successful practitioners. The orientation reference technique is an example of one way to minimize problems for learners when using virtual resources.

Future Research on Orientation References

The results of this study bring to light the challenge faced by individuals when learning with virtual resources. Improvements in virtual object rotation performance with orientation references may have important implications when training manual skills and when using virtual tools, but developing techniques to facilitate long-term learning is a viable and necessary goal. Future research should develop training practices to help learners enhance their ability to work with virtual objects without the need to augment them with artificial devices. Finally, future research should evaluate more challenging instructional practices with more complex material.

Acknowledgements

This research was supported by National Science Foundation Grant No. 0313237.

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