Tutoring 3-Dimensional Visual Skills: Dynamic Adaptation to Cognitive Level

Beverly WOOLF\(^1\), Matt ROMOSER\(^2\), Dan BERGERON\(^2\), Don FISHER\(^2\)

\(^1\)Department of Computer Science, \(^2\)Department of Mechanical and Industrial Engineering, University of Massachusetts/Amherst

General description

Visualization skills are central to topics such as recognizing molecular structure, constructing topologies, understanding manufacturing processes and interpreting engineering drawings. Historically, students, and especially female students, have had difficulty learning such skills. Teaching these skills is difficult and not typically attempted in the disciplines where the skill is needed. We have built a Rotation Tutor that will extend students’ ability to reason about 3D rotation. Since learning is maximally effective when targeted to a participant’s cognitive or developmental level, this tutor uses intelligent methods to dynamically adapt rotation problems to a user’s fluctuating skill level.

This Rotation Tutor is unique for several reasons. It tracks a participant while she infers the rotation of an object, models her skills and is sensitive to differences among an individual's spatial abilities. An expert system adjusts the level of complexity of the presented problem based on the number of subskills required and assumptions about the student’s skills. Participants will solve 3-D rotation problems. They will:

- **a)** Be presented with two 3-dimensional objects, Figure 1, and asked what rotation is required to rotate the object from the left to the right view.
- **b)** Suggest a rotation and click on the features of the needed rotation, Figure 2, (e.g., orthogonal axes, direction clockwise (C) or counter-clockwise (CW), and number of degrees (90, 180, or 270)).
- **c)** Be evaluated by the tutor reasoning about their spatial strategies. If the participant suggests the correct rotation, the tutor assigns a higher probability for the associated skills and selects a more difficult problem. When the average of the major skills rise above threshold, the participant graduates.
- **d)** Receive several levels of graduated hints, including an animated version of the participant’s rotation steps (“play” a 3D animation of the rotation, left top Figure 3), and several alternative correct solutions, if the solution is not correct.

Figure 1. The Tutor provides two views of an object (right) and the student identifies features of the rotation by clicking (left), Figure 2.
Understanding Spatial Strategies

We made detailed, quantitative cognitive models to describe spatial skills. Eye movement data was studied to identify the global stages, the more local processes within each stage, and the actual factors influencing the eye movement parameters (fixation duration, saccade size) themselves. We identified local strategies (e.g. 3D objects may be represented as the result of an interpolation based on 2D viewpoints that have actually been seen) and patterns of eye movements. We identified the optimal mix of part- and whole-task skill acquisition and determined what parts of the various visualization tasks could be singled out for skill acquisition and how we should optimally blend part-task and whole-task skill among individuals. Research shows that low spatial ability individuals both take much longer on average to perform these tasks and make many more errors than do high spatial ability individuals.

Expert System in the Rotation Tutor

The tutor contains an expert system to generate problems dynamically. Based on the participant’s current skill values, e.g., complexity of the object and rotation, the tutor isolates the “weakest-link” and targets new problems for that area. In this way, either the participant learns to recognize this feature by shear practice, or a remedial need is identified. If no clear weak area can be identified, or if each skill has been brought up to the same level as the other skills, the expert system defaults to a simple increasing difficulty approach. The expert system queues multiple related problems and keeps track of recent problems to avoid redundancy and boredom.

Figure 2. The student clicks features of the inferred rotations, including orthogonal axes, direction clockwise (C) or counterclockwise (CW) and number of degrees (90, 180, or 270).

We identified rotation characteristics that differentiated objects and identified various subskills that governed participant performance. We enumerated and categorized the total number of logically different rotations (assuming that the number of different levels of degrees of rotation is itself finite). Problems about the same topic can be of varying levels of complexity. The tutor adjusted the level of complexity of the presented problem based on the number of subskills required and the complexity of their application. The domain knowledge base coordinates the storage and retrieval of all objects available to the tutor and contains vital property values for each object, as well as all the views. The Student Model aids in pedagogical decision-making.

Figure 3. The tutor provides four levels of graduated hints (two shown) including an animated version of the participant’s proposed rotation steps (“play” button, left) as well as alternative correct solutions.
making and governs the maintenance of the participant’s “skill” values stored as a “probability known” coefficient for each of seven sub-skills: edges, faces, protrusions, notches, axes, degrees and direction, Figure 5. The Linear Approximation, Figure 6, returns the resulting probability for that skill and the Student Model triggers when a student has met the criteria for "graduation" to the next level, or when a sub-skill requires remediation. Graduation or remediation are adjusted dynamically based on the participant’s performance. Participants who have been struggling are allowed to “graduate” at a lower value or are remediated sooner, while stronger participants are pushed to graduate at a higher score and remediation is delayed. This mimics traditional on-ton-one tutoring.

**Evaluation**

Twenty-eight participants were evaluated. We compared performance of ten students with high spatial abilities, as measured on a pre-test, to the ten low spatial participants. The most interesting result was that with the additional practice provided by the tutor, the low spatial students improved their overall scores on the same rotation activity (pre to post) the same amount as practice helped the high spatial students. In a different test of spatial ability, high spatial students had an average increase in score from pre to posttest of 1.10 points. The low spatial students had an average increase of 8.4 points. This result was statistically significant. Students with advanced spatial abilities graduated from the tutor faster than students with lower spatial abilities. This allowed lower spatial students to receive more practice and feedback during their session while, at the same time, preventing high spatial students – who already have an intuitive grasp on the subject matter – from becoming bored or frustrated.

This IE is related to a short paper entitled: Tutoring 3-dimensional Visual Skills Dynamic Adaptation to Cognitive Level by Beverly Woolf, Matt Romoser, Dan Bergeron, and Don Fisher.