Computer-based Learning of Neuroanatomy: Cognitive science applied to anatomy education

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Students must learn to identify whole structures and sectioned structures.

In sectional anatomy, structures must by identified in two-dimensional sections that have been sampled from a three-dimensional structure.
Sectional Anatomy: A Challenge for Cognition

A single 3D structure can appear very different in sectional anatomy depending on the orientation and depth of the section.

Two very differently shaped 3D structures can appear similar in sectional anatomy.
Anatomical structures are densely packed together and irregularly shaped. There is little color or texture to distinguish them.
Why computer based learning?

• Computers offer unique approaches to visualization
  – View structures and relationships from many perspectives
  – Models can be repeatedly dissected

• Capability for repeated self-study
Our Goals

• Research based design

• Improve learning in sectional anatomy
  – Test hypotheses

• Ecological validity
  – Materials and procedures for real classrooms

• Comprehensive assessment
  – Learning over time
  – Transfer to new situations
  – Retention
Our Hypothesis

• Organization improves learning and memory for material
  – For example, see Bower, Clark, Lesgold, and Winzenz, 1969

• Hypothesis
  – Developing rich knowledge of whole anatomy may improve learning and retention of sectional anatomy
Research Design

“Whole then Sections”
Learn WA → Learn SA

“Sections Only”
Learn SA →
Our approach to learning: Adaptive Exploration

- High quality representation of the domain
- Tools for intuitive exploration
- Cycles of study, test, and feedback

The spacing effect in learning
See for example, Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006

The testing effect in learning
See for example, Karpicke, & Roediger, 2008
Neuroanatomical Model

Amygdala
Brainstem, Crus Cerebri, Internal Capsule
Caudate Nucleus
Cerebellum
Cortex
Fornix
Globus Pallidus
Hippocampus
Hypothalamus
Mammillary Bodies
Nucleus Accumbens
Optic Tract
Pituitary Gland
Putamen
Red Nucleus
Substantia Nigra
Subthalamic Nucleus
Thalamus
Ventricles

Images available through the Visible Human Project of the National Library of Medicine
Neuroanatomical Sections

Coronal: 60 serial sections
Sagittal: 50 serial sections
Axial: 46 serial sections
Participant could rotate the model 360 degrees in any direction, zoom in and out on the model, remove and restore individual structures, and select structures to find their name.
Whole Anatomy Learning Program: Test

Participant were asked to find and name as many structures as possible.
Participants had all of the tools that were available in the study phase. They were also provided with graphical feedback on their test performance. Structures named correctly were green. Structures named incorrectly were red.
Participants were presented with a series of sections from one of the three standard views. A slider was available that allowed participants to explore the sections. Participants could stop on any section and select individual structures to learn their name.
Participant were shown a series of sections, and were asked to name the structures indicated with arrows. The structures that were tested varied across the learning trials.
Participants had all of the tools available as in the study phase, but were provided with graphical feedback on their test performance. Again, green indicated a correct answer, and red indicated an incorrect answer.
Learning: Repeated Cycles of Study-Test-Feedback

A single learning trial consisted of …
   Study (3 min.) – Test (unlimited) – Feedback (3 min.)

The view of anatomy presented for learning alternated across learning blocks.

Learning was completed upon reaching 90% accuracy in three consecutive views.

Interleaving (alternating) material in learning improves retention
See for example, Taylor and Rohrer, 2009
Research Design

“Whole then Sections”
Learn WA → Learn SA → Transfer to Biomedical Images → Retention of Anatomy

“Sections Only”
Learn SA →
Testing Transfer to Biomedical Images

Magnetic Resonance Images (MRI)  Digital Photographs of Cryosections (Visible Human Images)

Question: Could our participants use the anatomical knowledge gained from our model to identify structures in biomedical images they had not see before?
Transfer Test: Uncued Recognition

Participants were given an image and asked to identify as many structures as possible in the image.
Participants were provided with the name of a structure and asked to find the structure in the image.
A structure was indicated by an arrow in the image, and participants were asked to provide the name of the structure.
Retention Test

Participants were given a series of sections. In each section structures were identified with arrows. Participants named the structures under the arrows.
Participants

- 72 undergraduate students
- 3 visits to the lab per week, one hour each
- On average, 5 weeks in the study
- Spatial Ability scores were balanced across the groups (ranging from 5\textsuperscript{th} to 99\textsuperscript{th} percentile in each group).
- No differences in spatial ability or rate of visits to lab between groups.
Is whole anatomy more efficient to learn?

![Graph showing the comparison between whole anatomy (WtS) and sectional anatomy (SO) in terms of percent correct over learning blocks.]

Participants learning whole anatomy began learning at a higher level of accuracy, learned at a faster rate, and completed learning in half the time of those learning sectional anatomy.
Does knowledge of whole anatomy improve the efficiency of learning sectional anatomy?

Participants in the whole then sections group (WtS) had higher initial accuracy in learning sectional anatomy and completed learning more quickly than participants in the sections only group (SO).
Error in Learning

Although the whole then sections group took longer to learn two views of anatomy, they made significantly fewer errors in learning than the sections only group.
How well is sectional anatomy retained over 2-3 weeks? Does knowledge of whole anatomy support retention?

Retention of sectional anatomy was still at the criterion for learning in the coronal view.

It fell just below criterion in the sagittal and axial views.

In the sagittal view, performance was significantly higher for the whole then sections group.

In subsequent research we found a greater benefit of whole anatomy across all views at retention intervals of 4-8 weeks.
Does knowledge derived from our model transfer to biomedical images? Does knowledge of whole anatomy support transfer to complex images?

<table>
<thead>
<tr>
<th>Uncued Recognition</th>
<th>Submit Structure</th>
<th>Submit Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI, Whole then Sections</td>
<td>MRI, Sections Only</td>
<td>VH, Whole then Sections</td>
</tr>
<tr>
<td>MRI, Sections Only</td>
<td>VH, Sections Only</td>
<td>MRI, Sections Only</td>
</tr>
</tbody>
</table>

Although performance varied across the tests, participants were able to transfer knowledge of anatomy to complex biomedical images.

There is no evidence in this study that knowledge of whole anatomy supported this process.
Summary

• Adaptive Exploration
  – Rapid learning
  – Transfer of knowledge to complex biomedical images
  – High levels of retention at 2-3 weeks
Summary

• Whole anatomy supports learning in sectional anatomy
  – Initial accuracy is higher
  – Learning is accomplished more quickly
  – Less error over the entire course of learning
  – Supports retention of sectional anatomy
Use in the classroom

- Collaboration with Sandy Sephtont (PBS), Ben Mast (PBS), Cynthia Corbitt (Biology), Jeff Petruska (ASNB), Robert Lundy (ASNB)
  - Undergraduate neuroscience
  - Graduate clinical neuroscience
  - Programs for high school students
Subsequent Development

- New approaches to integrating whole and sectional anatomy
- Longer retention intervals
- Transfer to biomedical images
- Evaluation in neuroscience courses
- Updated interface
- Increasing complexity of our neuroanatomical model
Publications


Papers in Progress


Naaz, F., Chariker, J. H., & Pani, J. R. Learning from graphically integrated 2D and 3D representations improves retention of neuroanatomy. (Manuscript in preparation).