Problem Solving Strategies Used in Anatomical Multiple-Choice Questions

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Abstract

Introduction: Multiple-choice assessments (MCQ) in the anatomical sciences are often perceived to be targeting recall of facts and regurgitation of trivial details. Moving away from this assumption requires the design of purposeful multiple-choice questions that focus on higher-order cognitive functions as opposed to rote memorization. In order to develop such questions, it was important to first understand the strategies that students use in solving multiple-choice questions.

Objectives: Using the think-aloud protocol, this study seeks to understand strategies students use in solving multiple-choice questions. Specifically, it seeks to uncover patterns in the reasoning process and tactics used when solving higher and lower order MCQ in anatomy. The research also provides insights on how these strategies influence the student's probability of answering questions correctly.

Methods: Multiple-choice questions were created at three levels of cognitive functioning based off the Ideas, Connections, Extensions (ICE) learning framework. The think-aloud protocol was used to unravel problem-solving strategies used by 93 undergraduate anatomy students as they solved multiple-choice questions.

Results: Sixteen strategies were identified through the oral and written think-alouds that students used to solve MCQ. Eleven of these have been described and supported by the literature, while the rest were utilized by our students when solving MCQ in anatomy. Domain specific strategies of Visualizing and Recalling, had the highest use. Personal Connection was a strategy that allowed students to achieve success in all ICE levels in the oral think alouds and in the I and E levels in the written think-alouds.

Conclusion: This research argues that it is upon us as educators to make learning visible to our students, specifically through the use of think-alouds. It also raises awareness that when educators facilitate the process of students making personal connections, it aids students in new knowledge being integrated effectively and retrieved accurately.

Keywords: Multiple-Choice Questions; Think-Aloud; Higher Order Thinking; Assessment

Introduction

Assessment is a central motivator for students and can influence the way they approach the learning of course material. As Boud noted, "What and how students choose to learn is, in large part influenced by what and how we choose to assess" [1]. Therefore, educators need to ensure that the structure and focus of our assessment plan does not inadvertently deter students from meaningful learning. In anatomy, multiple-choice exams, although not the only means of evaluation, are a signature assessment strategy [2], popular with instructors and

frequently considered necessary in the discipline. Students tend to associate multiple-choice exam format with memorization and may not see the need to modify their study approach to think critically about the material [3]. This often happens when MCQ are not purposefully designed nor aligned with the level of learning that is intended. The ICE model [4,5] and Bloom’s taxonomy [6] offer two useful frameworks in designing assessments that target various levels of cognitive function. The ICE model includes three components: Ideas, Connections and Extensions, which represent various frames of learning. Ideas are the fundamental, discrete pieces of information that make up the building blocks of learning. Connections are the relationships that students can form among discrete ideas and connecting new concepts to prior knowledge. Extensions constitute creating new learning and applying knowledge to completely new and novel situations.

There is a gap in the literature on domain general and specific strategies students use in solving MCQ. Domain general strategies can be observed to be executed across multiple domains, and are not dependent on content knowledge [7,8]. On the contrary, domain specific strategies are focused on content knowledge and depend on the domain the task is in [7,8]. Using the think-aloud protocol, this study seeks to understand strategies students use in anatomical education to answer both lower order and higher order MCQ and provides insight on how these strategies influence the student’s probability of answering questions correctly.

Methods

MCQ development

Six multiple-choice questions were designed to be included in this study. The questions were developed using the ICE Framework. A summary of the multiple-choice questions and the co-authors consensus on the ICE model ranking is provided in Table 1. Information was gathered from second-year undergraduate anatomy students at Queen’s University, a mid-sized research-intensive Canadian university. This research was approved by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board: DBMS-068-17.

Data collection

In this study, the think-aloud protocol was used to study students’ thought processes when responding to MCQ. The think-aloud approach [9] requires participants to verbalize their thought process as they solve a task. The focus is on the cognitive processes, rather than the final product, with the goal of making these processes as explicit as possible during task performance. Eleven oral think-alouds, followed by 82 written think-alouds administered through a questionnaire were used as the source of gathering data. One-on-one interviews were scheduled with those students who agreed to participate in the oral think-alouds. The interviews ranged from 40 - 60 minutes in length and were audio-recorded and transcribed. In the written think-alouds, students were asked about their use of strategies based on the level of question given to them.

Data analysis

The qualitative content analysis protocol [10] was followed to identify operators that students utilized when working through those questions. These operators explained the predominant reasoning processes used by the students. Two co-authors, independently analyzed the first three think-alouds from the participants, and then discussed the list of emerging operators from the data set. Once there was more clarity in these emerging procedures, similar coded units were clustered together into categories. This process helped us not only compare segments of data to each other but also to the identified categories to see whether the data were confirming or disconfirming the existing categories [11].

Results

Student strategies for MCQ

Sixteen strategies were identified through the oral and written think-alouds that students used to solve MCQ (Table 2).
<table>
<thead>
<tr>
<th>Correct Written Answer*</th>
<th>Question</th>
<th>Level in ICE</th>
</tr>
</thead>
</table>
| The trochlea is part of which of the following bones? | a. Scapula  
b. Ulna  
c. Radius  
*d. Humerus | I |
| Fissures divide the lungs into: | a. Lobules  
*b. Lobes  
c. Alveolar sacs  
d. Segments | I |
| A 20-year-old patient cannot abduct and medially rotate the thigh while running and climbing. Which of the following muscles is most likely damaged? | a. Semimembranosus  
b. Sartorius  
c. Rectus femoris  
*d. Tensor fasciae latae | C |
| In a given muscle fiber at rest, the length of the "I" band is 1.0 um and the "A" band is 1.5 um. What is the length of the sarcomere? | a. 1.5 um  
b. 2.0 um  
*c. 2.5 um  
d. 3.5 um | C |
| Kyphosis affects the structure of vertebrae causing forward rounding and abnormal curvature of the spine. Regarding the anatomy of the spine and associated axial skeleton, what may be the functional implications of this bony disorder? | a. shorter stature  
b. change in shape of the thoracic cavity  
c. odd shaped stomach  
*d. two of the above options | E |
| Why are the ligaments of the knee more prone to injury when the foot is planted (i.e. on the ground) with the leg extended rather than flexed?* | a. ligaments are loose  
*b. ligaments are tight  
c. they play no role in the stability of the knee  
d. the knee is easily moved under these conditions | E |

Table 1: Multiple-choice questions used in the think-alouds, and their alignment with I, C, or E level.
<table>
<thead>
<tr>
<th>Strategies</th>
<th>Description for the category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Words</td>
<td>Picked out keywords from the question and focused on them</td>
</tr>
<tr>
<td>Comparing Language of Options</td>
<td>Detect similarities or differences in the language of options and determine correctness</td>
</tr>
<tr>
<td>Read Aloud</td>
<td>Read the question and/or the options aloud</td>
</tr>
<tr>
<td>Asking a question</td>
<td>After reading the question or options asked a question regarding the problem</td>
</tr>
<tr>
<td>Delaying</td>
<td>Consider one of the options and decide that it should not be eliminated, the quality of that option should be evaluated later, after the other options are considered</td>
</tr>
<tr>
<td>Determining Question Type</td>
<td>Placing a label on the question in terms of type, for example as memorization, application, etc.</td>
</tr>
<tr>
<td>Correcting</td>
<td>Pointing out that they had been thinking incorrectly about a problem, correct it</td>
</tr>
<tr>
<td>Recognizing/Familiarity</td>
<td>Perceived a question or answer as correct or incorrect without a rationale, or due to it being familiar to them</td>
</tr>
<tr>
<td>Adding Information</td>
<td>Provided more information about one of the options, such as additional facts that were omitted or corrections to incorrect statements (i.e. presented incorrectly to serve as distractors)</td>
</tr>
<tr>
<td>Checking</td>
<td>Explained why an option is correct or incorrect by comparing the options with their knowledge or with the data provided in the problem</td>
</tr>
<tr>
<td>Predicting</td>
<td>Predicted what they expected the answer to be</td>
</tr>
<tr>
<td>Recalling</td>
<td>Retrieved basic facts or concepts from class, lab, notes, or the textbook i.e. declarative knowledge</td>
</tr>
<tr>
<td>Imitating</td>
<td>Imitating terms presented in the question, for example moving</td>
</tr>
<tr>
<td>Mnemonic</td>
<td>Utilizing a mnemonic device when responding to a question</td>
</tr>
<tr>
<td>Personal Connection</td>
<td>Expressing a personal connection to a topic presented in the question</td>
</tr>
<tr>
<td>Visualizing</td>
<td>Convert the written information to a visual, or draw written information as a visual</td>
</tr>
</tbody>
</table>

Table 2: The 16 strategies observed from the oral and written think-alouds.

Eleven of these have been already described and supported by the literature as procedures that learners frequently used in problem-solving [4-8]. Strategies like Checking, Comparing, Recalling and Predicting are associated with Bloom’s taxonomy [6,12] and the ICE Framework [4,5]. In this study five additional MCQ solving strategies were identified, that were practiced by our students when solving MCQ in anatomy. These strategies were Visualizing, Mnemonic, Imitating, Personal Connection and Recalling.

A strategy such as Visualizing is more dependent on a domain as the nature of anatomy plays high importance to the location of human structures in the body and their directional relationships to other structures. Methods used for instruction and studying anatomy often utilize visual aids. Mnemonics and Imitating were used as memory devices to help students remember and retrieve information. In Mnemonics particularly, students utilized phrases, rhymes, and acronyms to help recall concepts when answering the questions. As an example, Participant 2 used the mnemonic “dArk lIght” to remember that in a sarcomere the A band is the dark region and I is the light.
region. Conversely, with Imitating students use learned functions or movements of the human body from the course and utilize their own body to recreate an action or term that was stated in the question. In Recalling students used pattern recognition and relied on declarative knowledge to answer the multiple-choice questions. In Personal Connection students interacted with the question and made connections between the course content and an external context perceived as relatable to them. When analyzing the question levels with the strategies, domain specific strategies increasingly were used from I to C to E level questions, with a total of 51 of the domain specific strategies utilized when solving the E level questions.

**Associating strategies with question types**

Another goal was to further explore in what types of questions (I, C, or E) were strategies used and which of those strategies allowed for correct answers more than fifty percent of the time (Table 3). Recalling and Visualizing were the two domain specific strategies that were highly utilized across all levels of questions in both oral and written think-alouds. Recalling lead to correct answers usually (greater than 70%) across all levels in the oral think-alouds, and in the I and E levels in the written think-aloud question. Despite the frequent use of visualizing in the written think-aloud participants, it resulted in a high likelihood (> 50%) of getting the incorrect answer for question levels C and E. An example of using Visualizing and Recalling together is with Participant 5’s interview when answering the ‘kyphosis’ question they stated, "First I tried to remember what kyphosis was and then what maybe the function implications, I was trying to picture from my notes what it looks like".

Personal Connection was another strategy that was highly utilized in both oral and written think-alouds. During the oral think-aloud, Personal Connection helped participants come to the correct answer 100% of the time. During the written think-aloud, when Personal Connection was used in the levels of I and E it had an influence of being successful (I-100%, E-62%) versus using a Personal Connection in the connecting level questions resulted in the incorrect score 81% of the time. An example of using Personal Connection is during Participant 2’s oral think-aloud, they made a Personal Connection to help them come to an answer as noted by their statement, "Also at the beginning of the question, I thought about when I played sports to compare stable flexed position to unstable extended".

<table>
<thead>
<tr>
<th></th>
<th>Adding Information</th>
<th>Checking</th>
<th>Recognizing/Familiarity</th>
<th>Correcting</th>
<th>Predicting</th>
<th>Key Words</th>
<th>Comparing Language of Options</th>
<th>Delaying</th>
<th>Determining Question Type</th>
<th>Read Aloud</th>
<th>Asking a Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I level questions</strong></td>
<td></td>
<td></td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>11</td>
<td>8</td>
<td>23</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>C level questions</strong></td>
<td></td>
<td></td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>15</td>
<td>27</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>E level questions</strong></td>
<td></td>
<td></td>
<td>4</td>
<td>10</td>
<td>1</td>
<td>7</td>
<td>28</td>
<td>24</td>
<td>6</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

**Part B: Domain-Specific Procedures**

<table>
<thead>
<tr>
<th></th>
<th>Imitating</th>
<th>Visualizing</th>
<th>Recalling</th>
<th>Mnemonic</th>
<th>Personal Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I level questions</strong></td>
<td>11</td>
<td>40</td>
<td>35</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>C level questions</strong></td>
<td>23</td>
<td>34</td>
<td>30</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td><strong>E level questions</strong></td>
<td>12</td>
<td>22</td>
<td>32</td>
<td>22</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 3: Frequency of I, C and E level questions for both oral and think aloud procedures.
Discussion
Making learning visible

The findings suggest that as students are solving more in-depth level (C and E) questions they use more metacognitive strategies, although this is not necessarily helping them get the right answer. These students would benefit by being more selective of their use of strategies when solving MCQ. To help students be more selective, we as educators need to explicitly model our own mental processes so that students recognize how the experts take preexisting knowledge and their perspective of the problem, to sequentially manipulate the problem in order to generate a solution [13]. Decoding the disciplines, a theory of pedagogy, highlights cognitive bottlenecks for students [14]. According to this theory where these cognitive bottlenecks, such as activating prior learning or making connections in the case of this research exist, is where educators are not explicitly displaying to students how they use their thinking in their fields [14]. Educators may at times take for granted the knowledge they have, how they see the problems in the field, and the process they use to successfully solve this problem. Many of the mental steps taken by educators could be easily perceived, yet these steps are not translating well to our students. This supports that the bridge between teaching and learning still needs to be refined.

Narrowing the gap between novice and expert thinking

It was seen in our findings that students consistently are not achieving success particularly in the question level of connecting. This may be due to the differences in knowledge organization between experts and novices. Experts' knowledge is organized in web-like structures and connected intricately and in a meaningful way [15]. Conversely, novice learners organize and connect learned knowledge in a more linear and superficial way, so when asked to access their knowledge it is often based on loosely connected facts [15]. Making connections more explicit for the students encourages engagement, supports deeper learning, intrinsically motivates, and allows for application of knowledge [16,17]. It also creates a sense of difficulty that is desirable for students [18].

Students need to be given the opportunity not only to have guided instruction of strategies but also to practice these strategies. Think-alouds can be applied by students to practice higher order cognitive thinking strategies for answering multiple-choice questions. Students can monitor their reasoning process and apply specific strategies they feel will most efficiently and effectively result in a correct answer and promote deeper learning. Moreover, student think-alouds can be assessed by educators to provide specific feedback that can pinpoint areas of struggle in the students' thinking [13]. By providing a structure for students to build their connections around, it can help highlight to students where deeper connections can be made.

Limitations of the Study

As think-aloud procedures are time consuming, there was no opportunity to meet with the students beforehand and properly mentor them on ‘how to think-aloud’. As a result, while several problem-solving strategies were identified there might have been other thoughts or procedures that were not captured if the students did not state those. Also, it was at times difficult in finding what is the ‘right’ amount of probing. Yet, think-alouds remain a powerful vehicle in making visible metacognitive processes that often remain hidden to both the participants and researcher.

Conclusion

This research offered insights, through the think-aloud protocol, the mental processes and strategies students use when answering MCQ in anatomy. A total of 16 strategies were discovered to be employed by students, 11 of which correlated with previous literature. Domain specific strategies of Visualizing and Recalling, had the highest use throughout both oral and written think-alouds. Personal Connection was a strategy that allowed students from the oral think-aloud to achieve success in all levels, signifying that anatomical educators need to be aware that when students make personal connections it aids in new knowledge being integrated effectively and retrieved accurately. We argue for making learning visible to our students and supporting them in deconstructing their problem-solving strategies.

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Bibliography


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