Multi-Sensory Cognitive Learning as Facilitated in a FLASH Tutorial for Item Response Theory

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ABSTRACT

The objective of this paper is to introduce an application of multi-sensory cognitive learning theory into the development of a multimedia tutorial for Item Response Theory. The cognitive multimedia theory suggests that the visual and auditory material should be presented simultaneously to reinforce the retention of learned materials. This computer-assisted module is carefully designed based upon the preceding theory and usability study is pending to verify the claim.

Keywords: Multimedia, Hypermedia, Multi-sensory, Cognition, Cognitive Psychology, Item Response Theory, Measurement, Assessment.

1. INTRODUCTION

Since the introduction of the No Child Left Behind Act, assessment has become a pre-dominant theme in the US K-12 system. Schools that fail to demonstrate improvement in their students' test scores may eventually be restructured or even taken over by the state [1]. As a result of the highs stakes involved in assessment, many school districts have taken it upon themselves to develop their own assessments in order to identify and provide extra assistance to low performing students. The test developers within the school district are typically teachers who have no background in measurement theories and already have a full-time job within their classroom during the year. Consequently, the items and tests that are being developed may not be not valid or reliable measures of students' performance.

This study addresses the need to make such statistics accessible to K-12 teachers by providing a multimedia tutorial that helps them interpret their students' and the class' performance while also helping them to identify problems in test authoring so as to write better test items for future assessments. The tutorial is designed to help teachers understand and interpret the psychometric analysis of district tests by teaching item response theory (IRT), one of the most popular measurement theories in the field of educational assessment [2]. Unlike the classical true score theory, in which item difficulty is based upon the pass rate, IRT performs item attribute calibration and student ability estimation simultaneously, and thus it is considered a superior tool to the classical approach.

2. MULTISENSORY LEARNING

In order to make IRT understandable for teachers with no background in measurement theories, effective and user friendly instructional materials are needed. Computer-based materials have been developed by researchers and instructors to help students better understand the complex concepts in statistics and psychology courses [3, 4, 5]. Previous literature has explored the different ways people learn with multimedia applications. Multimedia may be defined as the combination of various types of media including text, images, sounds, voice, and video, integrated into a multisensory presentation that conveys various types of material [6, 7, 8]. A defining characteristic of multi-sensory learning is that it occurs when more than one sense is activated in the learning process.

Various modalities utilized in multimedia applications have been studied in order to identify the most effective combinations in facilitating learning. Mayer & Moreno [9] suggest that a modality effect exists, which states that individuals learn more when they receive both visual images and narration of text than individuals who receive the same material presented only visually and as on-screen text. The modality effect is based on working memory models which state that visual and auditory materials are processed in different areas of the working memory and both subsystems have a limited processing capacity. Therefore, using only visual or only auditory materials limits the processing capacity that is available, whereas employing both visual and auditory materials provides greater processing capacity and the material can be accessed from two areas of the memory as opposed to only one [7].

Mayer & Moreno [10] offered a cognitive theory of multimedia learning that integrates dual coding theory, cognitive load theory, and constructivist learning, and gives a basis for designing the most effective multimedia instructional materials. Dual coding theory states that visual and auditory materials are processed in different cognitive systems [11]. The cognitive load theory states that there is a limit to the amount of information that can be processed by the visual and auditory systems, and providing too much information with text, pictures, or sounds can overload the systems and inhibit learning [12].

Finally, the constructivist learning theory states that more meaningful learning occurs when individuals take relevant information from the material and integrate it with some of their other knowledge [9]. Based on the cognitive theory of multimedia learning, the most effective modality for instruction involves both audio and visual material presented simultaneously, so that the individual can use complete processing capacity as well as develop a visual and auditory representation of the material which the individual can use to make connections between the material [13, 14].

Likewise, the cognitive multimedia theory suggests that the visual and auditory material should be presented simultaneously to allow the individual to make connections between the types of material rather than presenting the material successively. Lindstrom [15] found that participants could only remember 20 % when they were presented with visual material only, 40% when they were presented with both visual and auditory material, and about 75% when the visual and auditory material were presented simultaneously. Similarly, Lee and Bowers [16] conducted a study with university students to determine the best combinations of media for learning. Compared to a control group, the pre-tests and post-tests of the treated groups revealed 12% more learning while reading printed text alone; 32% more learning while hearing spoken text and reading printed text; 46% more learning while hearing spoken text, reading text, and looking at graphics; 56% more learning while reading printed text and looking at graphics; 63% more learning while looking at graphics alone; and, 91% more learning while hearing spoken text and looking at graphics.

Research also suggests that adding extraneous sounds or visual stimuli that are not relevant to the material do not add to the ability of the individual to learn [7, 17, 18]. Many instructors believe that adding interesting facts or details to a boring presentation will make students more interested thereby increasing their ability to learn the material. However, the cognitive load theory states that there is a limit to the processing capacity of the visual and auditory systems [12, 14] found that participants receiving only narration and animation performed significantly better than groups receiving narration, animation, and integrated text , or separated text, on both measures of retention and application of the learned material. In addition, Mayer et al. [7] found that irrelevant video clips integrated into multimedia instructional material resulted in less retention of information although the result did not reach significance. By adding background music to a tutorial, Brünken, Plass, & Leutner [19] were able to examine the effect of extraneous and irrelevant audio on student's reaction time while simultaneously completing a task. The results indicated that the addition of the narration in the tutorial with the background music resulted in decreased reaction time during the task. This provides support for the cognitive overload theory and the modality effect, which suggest that the auditory and visual systems have a limited capacity to process information.

Further, some research has indicated that visual and audio integration does not result in increased learning. In a study by Koroghlanian & Klein [20], an instructional program for biology was given in four forms: one with text and static illustrations; one that had a bulleted outline accompanied by audio narration of the text; one that had text, illustrations, and animated instructional sequences; and one that had a bulleted outline, audio narration, and animated instructional sequences. Results indicated no significant differences between the types of instructional modes on a post-test measure. Similarly, Veronikas and Maushak [21] found no significant differences in learning for the three different modalities (text, audio, or a combination of text and audio) in college students' test scores following a tutorial on software application. However, they did find that students preferred to learn computer application with dual modalities (text and audio). The lack of significance detected in both studies may have been due to inadequate sample sizes and in turn decreased power. Another possible explanation for differing results may have been due to the complexity of the material covered in the multimedia presentation. Tabbers, Martens & van Merriünboer [22] tested the modality effect through a multimedia tutorial of non-technical subject matter, instructional design. Participants receiving visual text reported more mental effort while taking the tutorial than participants receiving the information through audio. However, participants in the visual conditions group scored significantly higher on a test of retention of the material and their ability to apply the material than participants in the audio conditions group. These results suggest that visual text may be more useful with non-technical subject matter.

3. USABILITY IN MULTIMEDIA

The usability of multimedia applications should also be considered when developing instructional materials. Usability is defined as the combination of a number of factors that affect the quality of a user's experience when using a particular program or system. These factors may include ease of learning, effectiveness, efficiency, error frequency, and satisfaction. Usability testing addresses these factors through a variety of methods by looking at how users interact with the prototype. It is usually an iterative process where participants are tested and the prototype is changed based on their feedback or test results [23] (and Usability.gov).

In a study that tracked eye-movement patterns during multi-media presentations, Faraday and Sutcliffe [24] provided guidelines for optimizing learning. These included using speech to reinforce an image; avoiding animation when a label is being mentioned; and, using animation to show results, as well as process. Najjar [25] points out that more interactive media such as user manipulation and periodic quizzes facilitate better learning.

The National Cancer Institute evaluated five different types of multimedia formats for educating people about lung cancer including text paperback booklet, paperback booklet formatted in HTML on the Web, spoken audio alone, spoken audio synchronized with text Web page, and Flash multimedia with animation, spoken audio, and text [26]. There were five testing session, one for each format, with 9 participants per session - 45 participants overall. Participants were shown their assigned program in its entirety; pre-test and post-test multiple-choice quizzes assessed participant learning. Participants were also given design description and short demonstrations of the other four formats. They were asked to rank preference for the five program formats (1-5) along with providing structured and open-ended comments about the usability of each format. Learning improved with the use of all formats, and Flash was preferred by 71.1% of the users regardless of user characteristics.

Loranger and Nielsen [27] conducted a usability study on 46 Flash applications including e-commerce, configurators, news and current events, maps and location finders, e-learning, entertainment, and productivity applications. Overall they found Flash to be a legitimate platform for complex web-based applications. Their results pointed to the ephemeral nature of Flash as an implementation technology used in web-based application. They found that 36% of users did not even make it from the main website to the actual application because the link was difficult to find or too flashy – reminiscent of an advertisement; to combat this they suggest making the link to the application basic text. Among those who did open the application, it was found that users rarely used the application more than once; so maximum impact on the first use is vital. Positive and negative findings were associated with the use of sound and animated objects. Both MacGregor [28] and Loranger & Nielsen [27] suggest using sound and animation judiciously.

The purpose of the following study is to develop a multimedia Flash tutorial on IRT, which is both user-friendly and grounded in cognitive processing theories, in order to maximize the effectiveness of the learner's ability to retain and apply the concepts described in the tutorial.

4. PROGRAM DESCRIPTION

This hypermedia tutorial, which is composed of two modules, is developed with the use of Macromedia Captivate®, Macromedia Flash®, Adobe PhotoShop®, SAS®, SPSS®, Microsoft Excel®, and Microsoft PowerPoint®. Hypertext and multimedia are two major features that are commonly found in many computer-assisted tutorials. However, rich media, such as over-use of animation modules, could lead to cognitive overload [12]. In addition, improper use of hypertext may interfere with instruction. Without prior knowledge pertaining to the subject matter, non-linear jumping across slides may not lead to a full understanding of the material [29]. Hence, contrary to popular practice, the introductory and the Table of Content page of this tutorial emphasizes the following: "Since some concepts are interrelated, readers are encouraged to go through the tutorial in a sequential manner" (Figure 1).

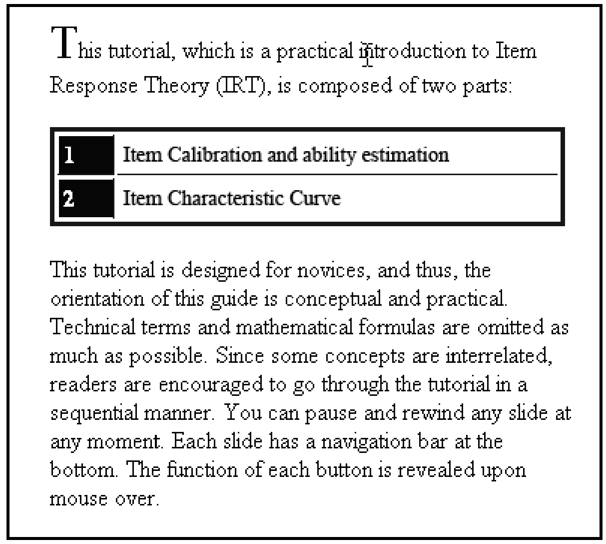
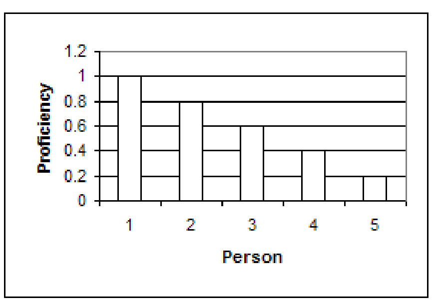


Figure 1. TOC of the tutorial

The content of the tutorial is based on a guide to IRT [30], which is cross-posted on the author's website and *Scientific Software International* ® website. The original text is composed of five chapters but this tutorial, as a pilot project, is reduced to two chapters only. The target audience for this program is undergraduate education students who have learned the basic concepts of statistics. Chapter One is concerned with item calibration and ability estimation whereas Chapter Two pertains to Item Characteristic Curve (ICC).

	Item 1	Item 2	Item 3	Item 4	Item 5	Average
Person 1	1	1	1	1	1	1
Person 2	0	1	1	1	1	0.8
Person 3	0	0	1	1	1	0.6
Person 4	0	0	0	1	1	0.4
Person 5	0	0	0	0	1	0.2



Student 2 has 80% proficiency. Student 3 has 60%. Student 4 has 40%. and Student 5 has 20%

Figure 2. 5x5 item-person matrix

Chapter one starts with a scaled down yet simple example: A data set with five items and five students only. Many instructors use real data sets to illustrate item calibration and ability estimation in a complex simulated environment, and as a result, students may experience cognitive overload. Therefore, the example used in this tutorial was simplified to increase understanding of the material. The example in Figure 2 is ideal as no item parameter can be estimated when all students could answer Item 5 correctly because there is no variation in the distribution.

Nevertheless, many successful scientific “thought experiments” start from “idealization,” in which the conditions do not correspond to the real world. In spite of using hypothetical cases, insight may still be gained when idealization makes every variable so simple that the user may “mentally manipulate” them without difficulty [31]. At the end of this session, the tutorial emphasizes that the example is an ideal case that is too good to be true (Figure 3).

	Item 1	Item 2	Item 3	Item 4	Item 5	Average
Person 1	1	1	1	1	1	1
Person 2	0	1	1	1	1	0.8
Person 3	0	0	1	1	1	0.6
Person 4	0	0	0	1	1	0.4
Person 5	0	0	0	0	1	0.2

This example is an ideal case, in which more proficient students answer all items correctly, and less proficient students answer the easier items and fail the hard ones. However, these results rarely occur in reality, and are just “too good to be true.” This ideal case is known as the **Guttman pattern**.

Figure 3. Guttman pattern: Ideal case

In Chapter Two, again we adopt the preceding strategy by presenting theoretical modeling but hiding empirical data. In testing regression, it is a common practice for instructors to overlay the data points and the regression line to offer a visual depiction of residuals. However, it would not work well in this situation, because in IRT there is person misfit and item misfit; in each of these categories there is model fit and individual fit; and these may be further analyzed through infit and outfit. The learner will most likely experience cognitive overload if the model and the data are presented together. Hence, our instructional strategy is to illustrate modeling with nice and clean graphics. For example, Figure 4 shows a typical ICC. The tutorial emphasizes that ICC depicts a theoretical modeling where, for instance, in the actual sample there may be no students with -5 skill level. Nonetheless, these extreme cases in a “what-if” scenario could clearly illustrate the point that if the person does not know anything about the subject matter, he or she will have zero probability of answering the item correctly.

The tutorial demonstrates idealization and modeling while also stressing the practical applications of IRT. One of the nice features of IRT is that the parameter values are centered at zero and thus the visual representation of item difficulty is very easy to interpret. For example, Figure 5 is a screenshot about how IRT can be applied to test construction by selecting items with different difficulty levels. As you can see, the bars of the

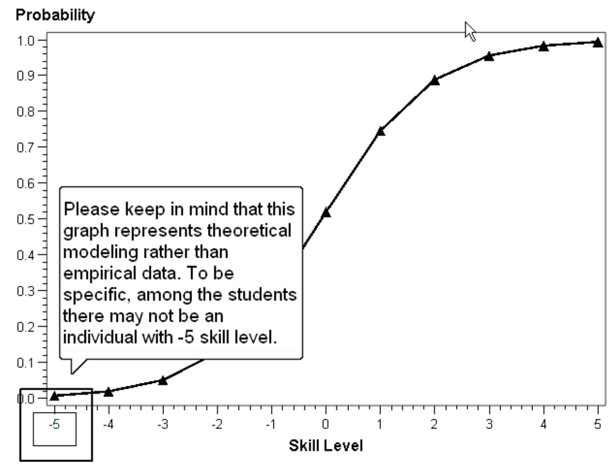


Figure 4. ICC

average items center around zero, hard items are located at the right side, and easy items are placed on the left side. It is notable that this visually compelling illustration is not used by popular IRT programs, such as Bilog, Winsteps, and RUMM. The bar chart in Figure 5 is generated in a SAS macro code written by Yu [32] and is imported into the multimedia tutorial**.**

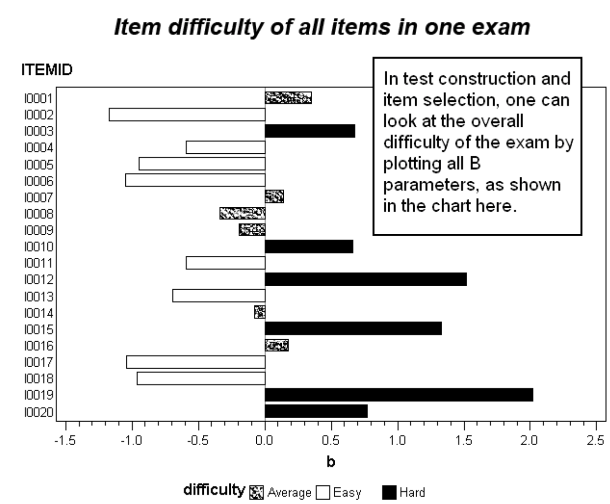


Figure 5. Item difficulty of all items

The computer-based multimedia program is accessible at http://www.creative-wisdom.com/multimedia/IRTTHA.htm.
Yu [31] has also prepared a PDF document that presents much of the program content. A version of this document can be viewed at
http://www.creative-wisdom.com/computer/sas/IRT.pdf

Once the tutorial is prepared, the next step will be to test it among our potential audience: undergraduate education students. A usability study testing the effectiveness of the use of audio narration will allow us to revise and modify the tutorial before we present it to our target audience of K-12 teachers working in assessment committees and task forces. Feedback from instructors will be collected during in-service professional development workshops as part of an ongoing and informal evaluation process. This process will help us fine tune the tutorial to increase its effectiveness. The multimedia program reflects our pursuit to provide a timely training tool for educational assessment while also enhancing statistical education. Use of the application and dialogue on this topic are encouraged.

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