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Effects of the Cognitive Level of Thought on Learning Complex Material

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ABSTRACT

The main goal here is to introduce a new perspective through which cognitive learning theory plays an active role in instructional hypermedia design and evaluation through testing educational mediums that elicit two distinct levels of cognitive processing for materials of different levels of complexity. Results indicate that if the cognitive level required is high and the materials are more complex, then a retardation effect occurs to learning, while a lower cognitive level requirement achieves better results will all types of materials.

This highlights the importance of taking cognitive requirements into consideration during the design of instructional hypermedia to produce "Cognitively Informed Systems". This perspective will allow a designer to analyze the same system from the perspective of how the presentation style and medium are likely to interact with students' cognitive processes during learning. This perspective is predicted to help lower the cognitive load demands of various instructional hypermedia systems in order to increase the educational impact of these systems and avoid any learning inhibitors to arise.

Keywords

Cognitive learning theory, Educational tutoring systems, Instructional hypermedia design, Mathematical educational systems, Interactive tutoring systems

Background

Cognitive learning theory represents here the part of the field of Cognitive Science that focuses on the study of how people learn and remember the information presented to them. In addition to being concerned with the transfer process from the presentation of the material to memory, it concerns the mental representation of concepts in memory as well as the cognitive load these concepts impose onto the cognitive system during the learning process. These aims qualify this theory as an ideal source of knowledge that is capable of enriching instructional hypermedia design. Oddly, this promising potential has only been identified by a few researchers including Jonassen (1991), van Jooligan (1999) as well as Albacete and VanLehn (2000a, 2000b).

Jonassen (1991) advocates the constructivist approach to learning where students are given several tools to relieve them from repetitive computation or to externally represent text they are required to recall as is usually done when writing on a paper, in order to allow them to focus on the learning task at hand. He adopts the assumption originally proposed by Lajoie and Derry (1993, Lajoie, 1990) that computers fill the role of cognitive extensions, by performing tasks to support basic thinking requirements like calculating or holding text in memory which caused them to label computers as "Cognitive Tools". Jonassen's (1991) central claim is that these tools are offered to students to lower the cognitive load imposed during the learning process which in turn allows them to learn by experimentation and discovery. However, no experimental evidence was presented to support these claims where students achieved more learning with these designs.

Wouter van Jooligan (1999) takes this concept a step further by proposing an environment that allows students to hypothesize and pursue the consequences of their hypotheses. They presented two systems; the first supports the hypothesis formation step by providing several windows that help students form their hypotheses and the second provides a formatted presentation of experiments already tested and their results in a structured manner. They also added intelligent support to the system by providing feedback to students to guide their hypothesis formation approach. Yet again the work was lacking of a proper comparative evaluation.

Albacete and VanLehn (2000a, 2000b) by contrast recognized the cognitive anomaly that exists between the naïve students' ill-structured knowledge of conceptual physics and the highly structured knowledge of experts in the field. Consequently their presented system concentrates on teaching students how the various concepts relate to each other. The evaluation of results exhibited no significant differences between the learning outcomes of the control group when compared to the learning outcomes of the experimental group. Albacete and VanLehn (2000b) then utilized alternative means of analysis to highlight various differences in learning between the groups. The first was through measuring the effect size as done by Bloom (1984) while the second was to compare results to the nationwide score on a standardized test. The third was to consider how much students who have different pretest scores learned when compared to each other.

Thus, a central goal of this paper is to present "Cognitively Informed Systems" as an approach to the design of instructional hypermedia systems by questioning the cognitive impact of the various modules within the system utilized to present information to learners. The answers to these questions would then be utilized to set a scheme of evaluation that is specific to this design in order to avoid the "no significant difference" trap that researchers fall into. If the evaluation pre and post tests are analyzed from a cognitive perspective then, different types of questions may elicit different levels of cognitive processing so simply adding the results of all types of questions is not likely to be sufficient to distinguish where student learning is facilitated versus where it is not.

Introduction to Cognitively Informed Systems

Instructional systems that take cognitive research findings into account qualify to be described as Cognitively Informed Systems by virtue of the cognitive information they carry within their design and evaluation stages. The justification for this type of system lies in the fact that learning is a cognitive task and this in turn implies that the designer of the learning environment should be acquainted with some of the findings known to date that concern the process and the mental representation of the topic to be learned. For example, if the topic to be taught is mathematical series, then the designer of the teaching system should be acquainted with concepts such as "cognitive load" which is defined as the amount of cognitive processing required to perform an operation. For example, the cognitive load associated with performing an addition of two numbers is less than that required for learning how to add.

A formalization of the main areas of contribution to qualify a system to be described as a "Cognitively Informed System" is as follows:

1. *Perception and Recognition*: In fields like Medicine, it is extremely important and difficult to alert student attention to particular aspects of images and scans that are critical to a patient's health which caused several theories to emerge. These include Marr and Nishihara's theory (1978) which argues that the main axes of the objects shown are utilized to recognize the object while Biederman (1987) contests that recognition can also be made by breaking the image into its primary components. Yet both theories unite in several basic principles including the coding of edges, grouping features to recognize higher order features and matching what is seen to structures stored in memory as well as accessing semantic knowledge about these shapes. Bruce and Younge (1986) proposed an influential model where they argued that familiar and unfamiliar faces are processed in different ways while a revised version of the model exhibits that recalling the name associated with a face differs from recalling information about the depicted person. Pane, Corbett and John (1996) designed an instructional system that exposed subjects to images that alter with time and through that may have caused them to focus their attention onto the particular points in the images that students required training in. However, their research question was to compare the learning effects of animation to carefully selected still images. So when they tested student learning with declarative questions they did not examine the "visual skills" students may have gained from the animated system that was not present in the still images even though these skills may prove priceless in a medical setting. Their conclusion was that animation and carefully selected images produce similar learning outcomes.
2. *Attention and Memory*: A central concern of instructional hypermedia is to attract students' attention to the points of importance in presented knowledge in order to promote recall of this knowledge at a later point in time. Theories of attention focus on limitations in the cognitive capacity to attend to a particular input by explaining possible causes for these limitations through various approaches (Broadbent, 1958; Treisman, 1964; Deutsch and Deutsch, 1963). In addition to this, a central division has been established between short-term and long term memory (James, 1890) where the term "short term memory" was eventually replaced by Baddeley and Hitch, (1974) to be "working memory". Atkinson and Shiffrin (1968) indicate that the working memory model is of relevance to activities such as mental arithmetic (Hitch, 1978) verbal reasoning (Hitch and Baddeley, 1976) and comprehension (Baddeley and Hitch, 1974) in addition to the task of recalling things from memory. One of the basic assumptions is that a student learning a skill has to recall the instructions as well execute them by recalling the given information. For example, someone learning how to drive has to recall how to drive in addition to paying attention to the road and the other cars there. Once this person acquires the skill of driving recall is reduced to the road situation because the driving task turns into a motor activity.
3. *Mental Representation of Concepts*: Albacete & VanLehn (2000a) attempted to utilize the findings on the structure of mental representation in Physics. They based the teaching strategy of the "Conceptual Helper"

by comparing the unstructured mental representation of students of conceptual Physics as compared to the highly structured mental representation of experts. The system, therefore, concentrated on helping students find the "links" that connect the domain concepts to each other. They defined these links as associations that are classically used in semantics to describe a relationship such as that between the concepts "parrot" and "birds" because the first belongs to the category of the second. By doing this, they assumed a symbolic mental representation which is primarily propositional (see e.g. Collins & Quillian, 1969; Rumelhart & Ortony, 1977). Issues of interference that adversely affects recall rose within this domain as is exemplified by the finding made by Baddeley, Grant, Wight and Thomson (1975). Subjects were informed of the locations of digits on a matrix verbally while they were visually tracking a light moving along a circular track and they were then asked to reproduce the matrix. Results showed that verbal messages that can be easily visualized are adversely affected while complex messages that cannot be visualized remained unaffected. This finding informs the design of multimedia systems to properly align them such that one does not retard learning in the other. There are many other findings within this domain capable of informing instructional hypermedia design.

4. *Natural Language Comprehension and Generation*: Communication in an educational setting can only be achieved if both parties arrive at a common interpretation of the written text in a hypermedia setting. Frazier and Rayner (1982) proposed a garden path model which earned its name because it can "lead up the garden path" by ambiguous sentences formed with correct grammar as in; "*The horse raced past the barn fell", "When Fred eats food gets thrown", "Mary gave the child the dog bit a band-aid", and "I convinced her children are noisy".* Additionally, there is a great deal of work on story comprehension of which one of the most successful theories was proposed by Kintsch and van Dijk (1978) where they indicated that story processing occurs at two levels; the micro structure where the details of the story are considered at the level of propositions and the macro structure level where the edited version of the micro structure is formed. The generalization that occurs is of particular interest to learning as some students tend to overlook important details when they generalize learned texts. Text generation by converse, involves generating language in forms as close to "natural languages" as possible and this is subject to various theories. The goals are usually to guide subjects towards self reflection and defending their own arguments. The setting usually involves an intelligent tutoring system that generates the text according to specific points it notices as in remediation of common errors. In short, this domain is vast, as it incorporates all the findings made in the study of "effective communication" and many findings could be used as a guide.
5. *Reasoning and Deduction*: Johnson-Laird and Byrne (1993) indicate that deductive reasoning is a central intellectual ability which is essential: "*in order to formulate plans; to evaluate alternative actions; to determine the consequences of assumptions and hypotheses; to interpret and formulate instructions, rules and general principles; to pursue arguments and negotiations; to weigh evidence and to assess data; to decide between competing theories and to solve problems.*" It is these domains that are affected by attaining an understanding of reasoning. For example, the mental models theory(Johnson-Laird and Byrne, 1991) assumes that models are formed according to present criteria such that "truth" is reinforced. Students therefore dislike assuming false facts unless they are explicitly stated. In the learning domain this implies that students are likely to accept presented materials at face value rather than question what if an exception emerges whenever instruction does not include concrete examples. The theory of Interpretation (Stenning and van Lambalgen, 2004) is based on the assumption that all tasks presented to students in natural language are subject to a number of possible interpretations as dictated by the semantics of the language. Following that it is quite possible for reasoning to occur in a logical fashion. This allows different learners to associate different interpretations with the same presentation materials if any ambiguities exist and the range of these presentations can be predicted by the logic of the presented materials. An example perhaps is the work done by Suthers, et al., (1995) which attempts to impose a particular "ideal" reasoning structure onto student reasoning.
6. *Cognition and Emotion*: Freud (1915, 1943) argued that very threatening or anxiety-provoking material is repressed from gaining access to conscious awareness and in turn cannot be remembered. Based upon this Gilligan and Bower (1984) indicate that recall is best when the mood of the student at recall matches that at the time of learning. Eysenck (1992) also argued that the main function of anxiety is to detect an environmental threat and as a consequence it may affect how widely focused a student's attention is. Images in a topic like medicine should be informed of these results.
7. *Cognitive Learner Differences*: Jonassen and Grabowski (1993) give a detailed account of basic learner differences that are embedded into cognitive learning theory. These include the differences between a visualizing learner who likes to imagine concepts versus the verbalizing learner who likes to learn through verbal communication. Albalooshi and Alkhalifa (2002) utilized this division to exhibit that a multimedia presentation of a concept that has both animation for the visualizer and verbal representation for the verbalizer exhibits reinforcement of one modality by the other. Ignorance of these differences may result in an ineffective design of the educational system.

This list contains all major areas of influence where cognitive learning theory can inform instructional hypermedia design and evaluation. To support and justify this framework, this paper presents a study of the interaction between the cognitive levels of thought that is elicited through the approach selected to present educational materials and two levels of complexity of educational materials.

The Interaction between the Cognitive Level of learning and the Complexity of the Learned Material

There are two basic dimensions of change that are at play whenever students are presented with educational materials. The first dimension concerns cognitive processes that are elicited during the learning task. It can be primarily visual, overloads working memory, requires complex forms of mental representation, is a reasoning task or can be affected by emotional states or individual differences. The second dimension of change that can affect learning is associated with the level of complexity of the presented materials where some concepts may be defined in terms of other basic concepts.

The study presented here concerns teaching students how to solve two basic types of questions commonly associated with mathematical series. The first is to evaluate the series by applying the various operations in order to attain the resulting value. The second type of question is when students are given the expanded version of the series and asked to give the expression. Both of these types can be taught for the addition, multiplication, division and power operations. Notice that the power operation is defined as repetitive multiplication which qualifies it to be more complex than multiplication. This instructional hypermedia system will examine the interaction between the two dimensions described above.

Determining the Cognitive Levels of Thought

The first dimension of change requires a careful analysis of various areas of influence that are extracted from the presented formalization. Undoubtedly, if we restrict the number of variables that are allowed to change then the reliability of the conclusions made increases. Consequently, the instructional system attempts to standardize all factors that affect cognition by unifying the colors and schemas of presentation except for the factor under analysis. This is the cognitive level of thought that is elicited by the presentation style and is based on Bloom's taxonomy of cognitive objectives (Bloom et al., 1956).

The lowest level is the knowledge level at which learning involves only the recall of facts, terminology, and methodology without any requirement to understand what is recalled. The next level is Comprehension at which elementary understanding is required as well as some use of the knowledge as in translating what was presented in the student's own words or interpreting it. This is followed with the level of Application which requires students to be able to generalize from given abstract rules to a form they can apply. Example questions include; determine the hypoteneous of a right triangle if one of the sides is of length 3 and the other of length 4.

The next level that concerns us here is the Analysis level which requires the extraction of features from a knowledge domain that can describe it. In addition, it also identifies the relationship between these elements. For example, if we consider mathematical series requires that students must gain the ability to distinguish some central features between the various operations. For example, if the main operation is subtraction, then the terms will be in decreasing order by a fixed amount. If on the other hand, the main operation is addition, they will be increasing by a fixed amount that is added to each. Recognizing such features is usually done at the Analysis Level of cognitive processing which is higher than that required for the evaluation of the various expressions.

The highest level of cognitive processing that is defined by Bloom's taxonomy is the evaluation level where judgments can be made about some of the content of the knowledge based upon criteria that is generated by the person or adopted from external sources. In order to raise the elicited level of cognitive processing to this level requires altering the basic approach adopted by the tutoring system when presenting information to students. A possible approach is to inform students of the solution patterns they are following so that they recognize their errors.

> "When a learner is engaged in a discussion about the learner model, he is reflecting upon his domain knowledge and experience re-calling and re-considering ideas of which he is aware."(Dimitrova et al, 2000)

A student therefore is offered the perspective of an instructor that considers the work of a student (in this case themselves) with the aim of evaluating it. The existing approaches for involving the learner in the modeling process include open learner models (Paiva and Self, 1995), collaborative student models (Bull et al, 1995) and interactive diagnosis (Dimitrova et al.,2000).

TAGUS is a workbench for dynamic learner modeling (Paiva and Self, 1995) aimed at externalizing and dynamically changing the learner model. The model itself is represented by Prolog clauses and learners can manipulate the model presented by selecting options and typing Prolog clauses in the control panel. In this system, both the educational system and the learner are external agents and interact with the model. Even though the system externalizes the student model, students find difficulty in understanding and interacting with this representation.

Mr Collins (Bull et al, 1995) is a student model that is open for inspection and negotiation with the student. The system and learner are allowed to have separate and possibly even different perspectives of the students knowledge and argue when they disagree with each other. Here the student model is externalized in tables, which contain domain rules, and the system and learner's estimate of levels concerning how much a student has learned. The communication environment is text based as selections are made from menu options. This may prove itself to offer a limited number of choices that a learner can reflect upon.

STYLE-OLM (Dimitrova et al.,2000) is an interactive diagnosis based modeler in an environment that teaches scientific terminology. A dialogue game model is suited for maintaining an interactive diagnostics dialogue and diagrammatic communication language provides a graphical externalization of the learner's beliefs. Communication is organized as an exchange of speech acts where dialogue moves are extracted from a framework for analyzing educational dialogues. So a student selects a question word from a list of possibilities and so on till the question is fully formed. However, the system itself has not been fully evaluated.

Determining Cognitive Load During Learning

The level of cognitive learning objectives was altered by altering the design of the educational module but this does not imply that while utilizing the same module that all types of series will impose comparative cognitive loads during the learning process.

In the field of mathematics, the basic operations are addition and subtraction. Multiplication can then be defined as repeated addition while division can then be defined as repeated subtraction. Power comes at an even higher level of processing as it is defined as repeated multiplication which in turn is defined in terms of addition.

These levels of processing suffer from the burden of interaction between the elements as it is defined by John Sweller (1994). The task students perform involves considering a series of terms of the form:

Series 1: $3 + 6 + 9 + 12 + 15$
Series 2: $3 + 9 + 27 + 81 + 243$

They are expected to dissect each number into its components such that they would comprehend the relationship that is preserved between them. One possibility is as follows:
Series 1: $3 \times 1 + 3 \times 2 + 3 \times 3 + 3 \times 4 + 3 \times 5$
Series 2: $3 \times 1 + 3 \times 3 + 3 \times 3 \times 3 + 3 \times 3 \times 3 \times 3 + 3 \times 3 \times 3 \times 3 \times 3$

The result of applying similar transformations to the first and second is just a step towards identifying what the summation notation is. For the first, it is immediately clear that the terms are multiples of 3 and the index that alters goes from 1 to 5. In the case of the second, we find that the index of the series has to be counted as it is represented as the number of times the number 3 is multiplied by itself. This places it at a higher level of complexity than that of series 1.

First of all, according to the definitions presented by Sweller (1994) both series satisfy the requirements of a complex task as resolving them requires a series of steps that are related or interact with each other. As complex tasks, these tasks are affected by varying cognitive load requirements of the task. Sweller (1994) defines the intrinsic cognitive load as that which is dependant on the task as directly dependant on the level of interaction necessary to complete the task. Series 2 shown above requires additional transformations when compared to series 1 because the index of the series notation cannot be readily extracted from what is shown as the number of repetitions must be counted. This leads to the conclusion that series 2 should require an intrinsic cognitive load that is higher than series 1 according to the rationale offered by Sweller (1994).

A Two Module System

In order to vary the cognitive levels of thought versus the cognitive load that a student is faced with can be done through a two module system. First of all, operations including multiplication and the power operation occur at the same cognitive level even though they impose two different levels of cognitive load onto a student's memory provided they are all presented by the same type of module.

The main teaching module is the interactive part of the system that allows students to insert key values and operations to evaluate the series in real time or give them examples of the reverse process if they insert some key values. This module helps them achieve the level of Analysis where they would recognize through the interaction with the system the features of each type of series to enable them to detect it.

The second main module is the "Mirror Modeler" and this part cannot exist in isolation of a teaching medium that also tests students. The results of the tests are taken and analyzed according to a table of errors that will be isolated from a specifically dedicated experiment. The system displays the probabilities associated with these errors to the student who made them and then solves three new questions in real time in front of these students while mimicking each student's errors according to the probabilities associated with them. This externalizes the whole solution process by displaying it live in front of the students. It allows them to process the information at the evaluation cognitive level where they would evaluate their way of working by comparing it to an ideal that is also displayed and calculated in real time in a window adjacent to the one displaying their way of solving the problem.

Consequently, the instructional hypermedia system teaches materials that require two different levels of cognitive load, through two modules that elicit two levels of cognitive processing to study the interaction between these variables. The goal is to exhibit that cognitive processing characteristics described in the formalization should influence instructional design by providing the means to lower the cognitive load during learning to avoid learning to be hindered by cognitive overload.

Design of the Instructional Hypermedia System

The model was developed using IBM's Java Visual Age, which is an integrated visual development environment that facilitates the generation of complex functions. Its main features include the ability to import Graphical User Interfaces (GUIs) and Java Beans that could be constant throughout several applications. The tool generates java applets as in the case of this project or Java Servlets as is required.

The instructional hypermedia system is composed of two main modules; an interactive tutoring module that elicits the analysis level of cognitive processing and a model generation and comparison module that elicits the evaluation level of cognitive processing as they were defined by Bloom's taxonomy.

Interactive Module

This module is composed of a tutorial section and a practice test section. The tutorial section of the system is composed of two main parts that introduce students to the concept of mathematical series by taking them through three examples where they generate the series from the summation notation and seven examples where they are shown how the summation notation is derived from the series. The system is interactive because it allows students to select some of the variable values and generates the series accordingly whenever possible. This problem is a complex one composed of three terms and is broken up into several parts that are calculated dynamically. Students are allowed to specify the starting and ending terms indicating the length of the resultant series and to be able to recognize how the series can change based on different starting and ending numbers. The second part of the tutorial is composed of seven examples of the more difficult task of extracting the notation from the series. The tutorial includes the steps to first select the starting and ending points followed by finding a common divisor and then the generation of the terms of the series to check that is the response is correct. It is difficult here to allow extensive interaction flexibility because the problems given are set problems and the system is primarily a teaching tool at this stage where all calculations are done online.

The practice test section is concerned with a more interactive practice session where students write the summation notation they believe to be the answer and are shown the resulting generated series. They can then compare this series to the original and practice any number of times they wish. At this stage students can select from the different given notations and are allowed to practice and see the result of each selection. They are also given advice of the probable cause of error based on the errors made. The number of options vary from one problem to another to test student learning and to expose students to more than one possible option.

The Model Generation and Comparison Module

This module is composed of two sections; a test section and a model comparison section. The test section is similar to the one described above because test questions are given to students with the exception that here, students are not shown the resulting series so they are not aware of whether or not their answers are correct. Students are showed three problems and they have to fill in several slots with the answers they believe to be true. In a sense, they break up the notation into a starting number, an ending number, etc. This allows the system to dynamically evaluate their responses. Student responses are then analyzed using an expert system that was specifically designed based on the errors revealed by experiment one.

The model comparison section utilizes simple Bayesian rules to extract the probability of that student makes each type of error and it generates a descriptive verbal model of the results. Note, however, that some of the defined errors depend on previously defined errors. This implies that they are not completely independent and the rules the modeler utilizes reflects that dependence. The modeler then shows students the ideal solution of several new sample problems while regenerating how they would solve the same problems using student models as a guide. The idea is to allow students compare their behavior to that of the ideal and allow them to reflect on the causes of their errors.

Evaluating the modules

In order to evaluate the modules three separate experiments were run on second and third year students at the University of Bahrain. The first experiment was run with the aim of categorizing common student errors in the task which was then used as a guide for the next two experiments. One group was tested before and after using the interactive tutorial module in order to detect any differences in their knowledge levels when exposed to this module. Another group was exposed to both the interactive tutorial module and the mirror modeler and tested in a pre and post test fashion. Do notice that it is not possible to test student learning before and after the mirror modeler as it cannot exist in isolation without the support of a tutoring system.

Experiment One

This experiment was conducted with the aim of categorizing common student errors in this task, and in order to identify if any cognitive load differences exist between the different operations. Its results were used as a basis for the expert system rules used by the modeler. 8 second and third year students from the University of Bahrain solved 6 summation questions each.

Materials

The questions used were specifically selected such that they relate to each other in a way that could be later compared for further analysis. Each student was given the expanded forms of the summations shown below.

Q. 1 $\sum_{m=1}^{10} 3^{(m+1)}$

Q. 4 $\sum_{i=1}^{10} 2i + 3$

Q. 2 $\sum_{m=1}^{10} 2^{m}$

Q. 5 $\sum_{i=5}^{15} 3i$

Q. 3 $\sum_{m=10}^{20} m^{2}$

Q. 6 $\sum_{i=1}^{10} i/4$

The summations shown include formats that target testing of the different operations. For example, the variable and constant positions are reversed for the power operation from $\mathbf{2^m}$ to $\mathbf{m^2}$ and for the multiplication operation from **3i** to **i/4**. Some of the digits were altered during these transformations to avoid making the questions predictable to students.

The aim of this design is to be able to highlight all different types of student errors with respect to the variations of the question format as well as to highlight the dependence of particular errors on particular question formats, in order to identify the existence of any variances in cognitive load requirements.

Results

A list of all possible errors was compiled and categorized as shown in table 1 based on student responses. This list is based on partitioning and an analysis of the surface structure of obtained responses to ensure that every possible error type is considered.

Table 1. The definition of each error type based on student responses

Error 1	The arithmetic operation in the chosen notation is incorrect.
Error 2	The integer number in the notation is incorrect.
Error 3	The starting number of the chosen notation is incorrect.
Error 4	The ending number of the chosen notation is incorrect.
Error 5	The number of terms in the resultant series of the chosen notation is less than the number of terms in the problem's series.
Error 6	The number of terms in the resultant series of the chosen notation is more than the number of terms in the problem's series.

The frequency of each type of error that students made per question is shown in table 2 with a maximum frequency of 8 for each cell.

Table 2. Number of errors students made in each question as classified by error type

	Error 1	***Error 2***	***Error 3***	***Error 4***	***Error 5***	***Error 6***
Q1	7	7	6	6	1	2
Q2	8	5	6	6	0	7
Q3	3	3	3	3	0	3
Q4	3	7	7	5	3	1
Q5	3	2	4	5	2	3
Q6	2	1	3	2	0	1

By definition Errors 5 and 6 are dependent on errors 3 and 4, consequently, if they are taken out of a Chi test calculation in order to have independent frequencies then results shown no significant differences with respect to subject behaviors between the errors, nor in general behavior with respect to the question. However, taking the data through a more detailed level of analysis using the Fisher exact test, reveals a significant difference with respect to the frequency of Error 1 between Questions 2 and 3 with $p < 0.013$ and Questions 1 and 6 with $p < 0.02$ and for Error 2 between questions 1 and 5 with $p < 0.02$ and questions 4 and 5 with $p < 0.02$.

Discussion

These results first and foremost highlight the main types of common errors that can exist in student responses some of which are compound errors such as errors 5 and 6 that are dependent on other factors as those contributing to errors 3 and 4.

The second issue is that student reactions of the differences in the complexity of questions were reflected in the results. Including multiple operations in the same series notation as in power plus addition or multiplication plus addition, offer the most challenge to students who performed this task as is evident above in Question 1 and Question 4 results in particular with error types 2 and 3. Following that in the ranks, comes the power operation which caused a difference in Errors 1 and 2 especially when compared to the multiplication and division operations.

These results confirm the predictions made that the added complexity offered by the power operation seems more cognitively taxing to students which in turn causes a higher frequency of student errors. At the same time, the level of overall difficulty is not affected as the results of the table as a whole does not show any significant differences through a Chi Test. This implies that the increased cognitive load, is not accompanied with added difficulty of the material, instead the task requires more thought processes, not thought processes that follow a completely different approach to solve the problem. In other words, the two tasks seem to unite in the way they can be solved and differ in their intrinsic cognitive load requirements. This is not surprising as the power operation is defined as in terms of repetitive multiplication so results support the basic assumption.

Now that the main types of error in this task have been defined and sufficient justification for the difference in cognitive load has been presented. The interaction between these two tasks and the two modules that elicit different cognitive levels of learning objectives can be studied through a specially designed system.

Experiment Two

The aim here is understand the effectiveness of having an interactive user interface to teach materials that require different levels of cognitive load. Students were, therefore, given a paper and pen test that is composed of three questions that test for the multiplication, power and division operation ahead and following their use the Interactive Tutorial Module.

Subjects

21 students from the University of Bahrain participated as volunteers in return for course credit.

Materials

The questions used were specifically selected such that they relate to each other in a way that could be later compared for further analysis while ensuring they are not identical to avoid allowing students to simply repeat the answers they gave in the pretest. Students were given the series of numbers shown below and asked to reproduce the summation Notation that is to the left of each series shown.

Table 3. he pre test series given to students is shown to the right and they must reproduce the notation shown to the left

$\sum_{i=1}^{10} i/4$	S=1/4 + 1/2 + 3/4 + 1 + 5/4 + 3/2 + 7/4 + 2 + 9/4 + 5/2
$\sum_{i=1}^{10} 2^i$	S = 2 + 4 + 8 + 16+ 32 + 64 + 128 + 256 + 512 + 1024
$\sum_{i=2}^{11} 3i$	S= 6 + 9 + 12 + 15 + 18 + 21 + 24 + 27 + 30 + 33

Table 4. he post test series given to students is shown to the right and they must reproduce the notation shown to the left

$\sum_{m=3}^{12} 11m$	S=33 + 44 + 55 + 66 + 77 + 88 + 110 + 121 + 132
$\sum_{m=2}^{11} 3^m$	S = 9 + 27 + 81 + 243 + 729 + 2187 + 6561 + 19683 + 59049 + 177147
$\sum_{m=1}^{10} m/7$	S= 1/7 + 2/7 + 3/7 + 4/7 + 5/7 + 6/7 + 1 + 8/7 + 9/7 + 10/7

The mapping between questions types is as follows:
Question Type One is Q1 in the Pretest and Q3 in the Post-test
Question Type Two is Q2 in the Pretest and Question 2 in the Post-test
Question Type Three is Q3 in the Pretest and Question 1 in the Post-test.

Results

The number of errors produced by question type in the pre and post tests in addition to the percentage improvement is shown in table 5.

Table 5. he number of errors in the three operations in the pre and post tests

	Division	Multiplication	Power
Pre-test	56	70	54
Post-test	14	25	28
Percentage Improvement from total	33.3%	35.7%	20.6%
Chi Test Significance $p <$	*0.0000*	*0.0000*	*0.0007*

If the number of errors in each column and the number of correct question parts are compared for the pre-test, then no significant differences emerge. This implies that the three types of questions do not differ in their difficulty. Running the same test on the post-test data gives a Chi Value of 5.914 with $p < 0.05$ so student learning different from one operation to the next.

A Chi Yates value of 7.299 with $p < 0.007$ emerges upon more detailed testing between the division operation and the power operation. A large difference also exists between the multiplication operation and the power operation but it is not a significant one.

Additionally, the significant results of a comparison of the pre and post tests according to error type are shown in table 6.

Table 6. umber of Errors made by students classified according to error type in the three operations Classified by Error type

	Interactive Tutorial Pretest No of errors of this type	Correct question parts	Interactive Tutorial Posttest No of errors of this type	Correct question parts	Chi Yates Significance
Question 1-Multiplication					
E1	15	6	6	15	0.014
E3	17	4	5	16	0.001
E4	17	4	6	15	0.001
E6	16	5	5	16	0.002
Question 2-Power					
E1	14	7	6	15	0.031

E6	12	9	5	16	0.059
Question 3-Division					
E1	13	8	3	18	0.004
E3	12	9	3	18	0.010
E4	13	8	3	18	0.004
E5	13	8	2	19	0.001

Discussion

Results obtained in table 5 show that no significant differences in difficulty exist as students start the learning process but differences do exist when we compare the amount of learning they achieve for each operation while using the same interactive instructional system. The only remaining identifiable cause for this difference is when the division operation is compared with the power operation and this supports the assumption that dictates the existence of cognitive load differences between the two concepts.

It is glaringly obvious in table 6 that the improvement students achieve in multiplication and division spanned a larger subset of error types than in the power operation. Therefore, one may safely conclude that although learning occurs for all three operations while using the interactive module, the total gain and nature of this learning differs from one operation to the next, in a way that consistent with the implications of the cognitive load theory.

All this occurs when the instructional hypermedia module elicits the analysis level of cognitive learning objectives, so what may occur if it demands a higher level of cognitive processing? This is what the next experiment will investigate.

Experiment Three

The mirror modeler works by extracting errors from student responses to a set of questions and identifying common error types in order to mimic the way that students solve this type of question. A student learns by observing the process and evaluating it by comparing it to an ideal solution process.

Consequently, this module does not offer novices any basic information about the subject matter and this means that testing it in isolation of other learning modules is meaningless. This leaves two possible options; to introduce a simple textual explanation of the subject matter to the student prior to exposure to the mirror modeler or to expose them to the interactive module tested in the previous section. The first option involves introducing new material that has not been properly tested for its learning impact, while the other involves the use of a very well assessed module that is the one to be compared to this one.

Consequently, both modules were presented to the students in a consecutive fashion while testing is done prior to the first and following the second utilizing the same questions used in experiment two.

Subjects

12 students from the University of Bahrain participated as volunteers in return for course credit.

Materials

The materials were identical to those given to students in experiment two.

Results

Analysis of student responses showed in general that the number of errors made in the Pretest were 37 and the number of errors made in the Post-test were 17 with a probability of **p** <.001 of this happening by chance. Table 7 shows the number of errors according to question type.

Table 7. Number of errors in the three operations in the pre and post tests

	Division	Multiplication	Power
Pre-test	6	21	10
Post-test	0	1	17
Percentage Improvement from total	8.3%	27.8%	-9.7%
Chi Test Significance p <	*0.037*	*0.000*	*0.200*

Discussion

The results of using the interactive tutoring module followed by the mirror modeler shows a clear difference between the division, multiplication and power operations. The division and multiplication operations both recorded significant improvements in student levels while the power operation was not significantly affected by the modules that are presented. This is further evidence to support the assumption that the difference between the cognitive load requirements of the multiplication and division operations when compared to the power operation caused a serious difference in the amount of learning achieved as students utilized these two modes of learning. It is therefore, not wise to assume that any educational system that is successful in teaching a particular concept will be equally successful in others without running a comparative analysis of the cognitive load requirements. Further results, however, can only be delineated from the data when it is compared to the results of experiment two.

If this is done, then we find that students learned from the interactive hypermedia system in all operations, but learning was to a higher degree in the division and multiplication operations which require a lower cognitive load than in the power operation. Consequently, the results obtained in experiment three for the power operation can only be obtained if the mirror modeler hindered learning for the power operation.

General Discussion

This paper shows that students mentally process the power operation in mathematical series in a way that is different to the way they process the multiplication operation. The difference does not seem to exist in how the operation is carried out because the first experiment showed no distinction with respect to difficulty. Instead, results indicate that the cognitive effort required by one exceeds the cognitive effort required by the other.

Both operations were taught by two modules that require different cognitive levels. The first requires students to recognize features that distinguish the behavior of the two operations by offering interaction. The second places a student in a teacher's shoes and expects that student to compare their own behavior to the ideal solution process.

If cognitive processing characteristics have no effect on learning, then both operations of differing complexity would be learned at the same rate in the same module. However, the fact that learning of the power operation was hindered by the mirror modeler while that of the multiplication operation was fortified gives a strong indication that cognitive processing overload may inhibit learning.

Reducing cognitive load therefore required an understanding of the relevant cognitive areas that were presented earlier in this paper which results in the development of what may be described as Cognitively Informed Systems.

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