# Investigating Limited Perception Effects from a Cognitive Science Perspective

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**Abstract**

Limited working memory capacity has come up frequently in literature especially with respect to learning. It provided an explanation to a number of phenomena that are observed in learning. However, it does not explain how experts learn better from diverse sources while novices learn better from a clear limited source of information. Nor does it explain how sequential presentation of a cognitively demanding task is accomplished with ease when compared to a split-attention presentation on the same screen of the same task. This paper, investigates the effects of limited attention. This implies that students are limited by how much information transfer can take place in parallel which may be due to perceptual effects. This informs technology based systems in particular that are capable of parallel information presentation through multiple windows.

**Keywords:** Learning; Working memory; Perceptual System.

## Introduction

Moreno and Mayer (2000) present several experiments where they test different multimedia combinations in order to examine the various cognitive characteristics of the learner. The aim is to produce multimedia design principles based upon cognitive theory assumptions. One of these is the split attention principle, which dictates that students learn better when the instructional material does not require them to split their attention between textual information and animation on the same screen. If information is represented as an animation with auditory narration, then they do better than those who have to split their visual perception between the text and animation. Both groups were strictly monitored for time. Moreno and Mayer (2000) explain their results by referring to the cognitive load theory (Sweller,1988; Chandler & Sweller, 1992) which dictates that working memory of the visual field is limited.

Tabbers, Martens and Van Merriënboer (2001) replicated the findings of Moreno and Mayer (2000) and then allowed students in a second experiment to take as much time as they wish to consider the two parts of the screen. The differences between those who had to split their visual attention and those who listened to auditory narration disappeared.

If the limits imposed are on the perceptual system's memory, then they are more likely to be sensitive to time then if the limits are imposed from working memory.

Schnotz and Kürschner (2007) indicate that working memory by definition has to hold the current problem state, the goal state, any sub-goal states as well as any relations or operators continually in working memory until the task is accomplished. By contrast, the visual field's attention mechanism is restricted by the items that can be attended at any point in time. Humans are not capable of seeing behind their backs, for instance, but if they have enough time, they can turn around and look to see what is behind them.

This implies that the results obtained by Tabbers, Martens and Van Merriënboer (2001) indicate that the restriction detected by Moreno and Mayer (2000) does not lie in the working memory that is expected to hold all problem states as defined by Schnotz and Kürschner (2007).

This paper will investigate the effects of limited perception effects during learning which implies that the reception mechanism places a limit on the amount of information that is received in parallel as it is transferred to the working memory's limited cognitive load. Therefore, the working memory's capacity acts a limited store to which the information is transferred and the bandwidth dictates how fast the information is received but it is at least a bit smaller than the capacity of working memory.

An analogy to clarify this is that students may be asked to read four pages of sequential information explaining a case study only to later analyze it as a unitary case. On the other hand, a student may be show four sheets of paper and asked to read them all in a very limited amount of time.

The limitation in working memory would still exist, but the perception limitations would also exist so received information may arrive more efficiently sequentially rather than in parallel.

This paper will present support to this claim, through an interactive mathematics tutorial system that will test two presentation approaches. The paper will start by reviewing relevant work to present evidence of the phenomenon in existing literature. It will present the approach followed to test the phenomenon and expose it. That will be followed with a discussion of the impact of these findings on educational systems that utilize modern technology.

## Background

One of the first theories developed on limitations in perception is the Broadbent Filter model (1958). The theory identifies the limited capacity of the perceptual system. It argues that the perceptual system considers the physical features of all stimuli (pitch, color, orientation) and utilizes this to select the stimuli that will be attended to. The theory explains that this selection is necessary because the processing of semantic nonphysical features is severely limited.

However, this theory was quickly superseded as a variety of experiments (Moray, 1959; Treisman, 1960) indicated that participants engaged in one task are sometimes influenced by perceptual channels unrelated to that task. A number of theories eventually emerged to explain the various traits and limitations of working memory (Atkinson & Shiffrin, 1968; Baddeley, 2001; Baddeley & Hitch, 1974).

One of the influential theories in educational psychology is Cognitive Load theory. This theory has constituted a focal point of enriching instructional design with cognitively based information. The basic assumption is introduced by Sweller (1988; Sweller et. al., 1990) that cognitive load refers to any demands on working memory storage and processing of information. Working memory refers to the structures and processes used for temporary storage and manipulation of information as opposed to long term memory where memories are kept for a long duration of time. Miller (1956) was one of the first who noticed the limitations of working memory and associated the limitation with seven chunks representing seven information blocks that can be remembered at one time. If information can be represented in a form that is more meaningful or that is composed of no more than these blocks, then it is more likely to be remembered.

Cognitive load was later split up to describe the additive sum of intrinsic load, extraneous load and germane load (Sweller, 1988; Sweller et. al., 1990; Sweller et. al., 1998). Intrinsic load is the load that is required by the nature of the task itself while extraneous load represents the unnecessary load that is required by the presentation approach that is utilized when presenting the task to learners. Germane load on the other hand, is a recent addition to the above two and describes a positive load effect that increases load requirements of the learning task in a positive fashion (Sweller, 2005).

However, there are two phenomena that are difficult to explain with existing theory. The first will be described as "the expert effect" and was initially detected by Kalguya et. al. (1998). They found that when learner expertise increases, these learners achieve more efficient learning from multiple sources of information while less experienced learners in the same topic face difficulties when splitting their attention among different sources. Another type of the expert effect was detected by Kalguya et. al. (2000) and was later supported by Leahy et. al. (2003). Non experts learn better from diagram plus auditory presentation while experts learn better from only the diagram presentation.

The second phenomenon is when students are presented with a split page with a diagram and text then their learning is affected by whether or not they are given enough time to go over the two presentation types. If they are allowed sufficient time, there is no difference between the animation plus text (split attention) and the animation plus auditory explanation.

These findings imply that the bottleneck that exists has characteristics that can be further investigated in detail. In fact, Schnotz and Kürschner (2007) indicate that reduction of cognitive load is not always helpful to learning, and that expertise is a critical variable that influences learning such that the intrinsic cognitive load is negatively associated with the level of expertise a learner has. This may explain why experts learn more from multiple sources while novices have difficulty splitting their attention between multiple sources of information.

Schnotz and Kürschner (2007) explain this associated by defining learning as changes that occur in long term memory and is therefore not a function that is dependent on working memory. Consequently, learning as a process is not affected by limits in working memory.

This indicates that the interaction between long term memory and working memory is not subject to limitations because expert learners can apply new concepts interactively without any restrictions in working memory capacity. However, they do not investigate the role of perceptual limitations in this explanation. Experts may not attend to all multiple sources of information, for example, which may cause the reduction in intrinsic load of expert learners that they report.

On the other hand, when these learners are novices, they require a higher interaction with the outside world and a higher amount of information that is received through the perceptual system. If time is restricted, and information is provided through two types of media presentations, then they require more time to achieve similar levels of experience, than those who are exposed to visual plus auditory presentation.

This implies that novices rely on their perceptual system to provide them with all necessary information, while experts already have part of the information stored in long term memory. This would explain why experts can learn from diagrams alone while novices need the auditory narration to learn better.

In a sense, both the expert effect and the multi-sensory effect indicate a form of "perception traffic jam" that occurs where working memory's reception bandwidth is limited and if enough time is provided or if backup processing occurs with the assistance of long term memory, then this information jam is resolved. If, however, the cognitive load limit is exceeded, learning is hindered or even negatively affected.

This paper will present an experiment that will expose students to two different settings to compare the cognitive load differences between them.

## Investigating Limited Perceptual Effects

The topic is mathematical series of the format 1+2+3+4+..+100 that can also be represented as a mathematical notation with a summation sign and a starting and ending point as well as a variable to represent the change from one term to the next. The example shown above will therefore has the summation format;

$$\sum_{i=1}^{100} i$$

The term "i" in this case is a simple term but it may appear with a number that is added to it as in i+2, or a number that multiplied as in 2i or even with a power operation like $2^i$ or $i^2$. These operations are in rising degrees of complexity to the learner as would be expected.

This allows the parallel investigation of perceptual limits as well as complexity effects of the materials. The main goal of the experiment is to distinguish serially presented materials of the same lessons versus presenting a great deal of information in parallel. There should be no difference in the amount of information that is presented serially from the information presented in parallel to ensure that the comparison is a valid one.

The interactive tutoring system utilized to present information starts by explaining basic information to students and then presents them with an Interactive Module. They utilize this model by typing different numbers and watching as the system generates the series these numbers will generate. At this stage they face one screen with the information displayed reducing any extraneous cognitive load requirements to a minimum.

### Sequential Demonstration Module

Since the primary concern of the tests run here is to identify if sequential presentation of information has a different impact from split-attention presentation of information with the same load requirements, students were tested as one or the other stage of learning.

One group of students who completed the interactive learning phase went on to a practice test session. Here, they answer seven questions which display a mathematical series and ask them to write the notation. When they write the notation, they can generate the series from what they wrote and compare this to the series in the question. The questions are all accessed from a page that displays a list of test question numbers, so learners can only review one question at a time sequentially. They are tested following this stage of learning using a post test.

### Split-Attention Demonstration Module

The second group of students completes the interactive learning phase, then goes on to a second presentation of the same type of generated solution. The difference here is that they face a split-attention task. On one top of the screen, they see their approach to solving a task, while on the bottom of the screen they see the ideal approach to solving the task. Their mistakes are made clear by comparison with the ideal while displaying both on the same screen. This group is also tested with a post test. A sample screenshot is shown in Figure 1.

## The Evaluation Experiment

The experiment was run over a four and half hour duration with two randomly distributed groups of students who completed the task in return for course credit. They were all third and fourth year students majoring in BSc computer science and Computer Engineering. The first group was composed of 32 students and the second group was composed of 16 students.

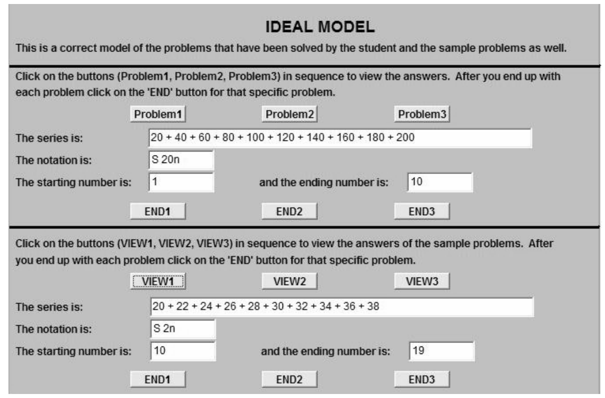


Figure 1: A screen shot of the Split-Attention Module.

### Results

The results of the Pre and Post test of the Sequential group are shown in table 1. The last line shows the average marks obtained by students out of 6.

Table 1: The results of the Sequential Group

| Q1 | Q2 | Q3 | Q1 | Q2 | Q3 |
|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 6 | 1 |
| 0 | 1 | 0 | 1 | 6 | 1 |
| 1 | 2 | 2 | 6 | 6 | 6 |
| 1 | 1 | 1 | 6 | 6 | 6 |
| 1 | 1 | 1 | 6 | 6 | 6 |
| 1 | 2 | 2 | 6 | 6 | 6 |
| 2 | 2 | 1 | 2 | 1 | 2 |
| 2 | 2 | 6 | 5 | 6 | 6 |
| 2 | 2 | 6 | 5 | 6 | 6 |
| 2 | 2 | 3 | 4 | 6 | 2 |
| 2 | 2 | 2 | 6 | 1 | 3 |
| 2 | 6 | 3 | 6 | 6 | 6 |
| 2 | 2 | 2 | 6 | 1 | 3 |
| 2 | 2 | 5 | 1 | 6 | 1 |
| 2 | 6 | 3 | 6 | 6 | 6 |
| 2 | 2 | 3 | 6 | 6 | 6 |
| 2 | 6 | 6 | 4 | 6 | 6 |
| 2 | 2 | 1 | 2 | 2 | 2 |
| 2 | 2 | 3 | 4 | 6 | 2 |
| 2 | 6 | 3 | 6 | 6 | 6 |
| 2 | 2 | 3 | 6 | 6 | 6 |
| 2 | 2 | 1 | 2 | 1 | 2 |
| 2 | 3 | 3 | 6 | 6 | 6 |
| 2 | 3 | 3 | 6 | 6 | 6 |
| 2 | 2 | 5 | 1 | 6 | 1 |
| 2 | 3 | 1 | 4 | 6 | 4 |
| 2 | 6 | 3 | 6 | 6 | 6 |
| 2 | 2 | 1 | 2 | 2 | 2 |
| 2 | 6 | 6 | 4 | 6 | 6 |
| 2 | 2 | 3 | 6 | 6 | 6 |
| 2 | 2 | 3 | 6 | 6 | 6 |
| 2 | 3 | 1 | 4 | 6 | 4 |
| *1.75* | *2.75* | *2.69* | *4.44* | *5.13* | *4.31* |

The results of the split-attention group are shown in table 2. The last line shows the average marks obtained by students out of 6.

Table 2: The results of the Split-attention Group

| Q1 | Q2 | Q3 | Q1 | Q2 | Q3 |
|---|---|---|---|---|---|
| 6 | 1 | 6 | 6 | 6 | 6 |
| 4 | 1 | 2 | 5 | 6 | 1 |
| 4 | 1 | 2 | 5 | 6 | 1 |
| 6 | 1 | 2 | 6 | 6 | 5 |
| 6 | 6 | 5 | 6 | 6 | 3 |
| 6 | 2 | 5 | 6 | 6 | 6 |
| 6 | 2 | 5 | 6 | 6 | 6 |
| 6 | 1 | 6 | 6 | 6 | 6 |
| 6 | 6 | 6 | 6 | 6 | 2 |
| 6 | 6 | 5 | 6 | 6 | 3 |
| 6 | 1 | 6 | 6 | 6 | 2 |
| 2 | 6 | 6 | 6 | 6 | 6 |
| 2 | 6 | 6 | 6 | 6 | 6 |
| 6 | 6 | 6 | 6 | 6 | 2 |
| 6 | 1 | 2 | 6 | 6 | 5 |
| 6 | 1 | 6 | 6 | 6 | 2 |
| *5.25* | *3.00* | ***4.75*** | *5.88* | *6.00* | ***3.88*** |

The three way Analysis of Covariance test (ANCOVA) of the Sequential group resulted in F=1.42 and $p < 0.25$ while the three way ANCOVA test for the split-attention group resulted in F=16.49 with $p < 0.0001$. It is also worth noting that students who received an average of 4.75 out of 6 in a pretest scored lower in the post test following the split-attention task with an average of 3.88 which implies that they got more confused and made more mistakes following the use of the system.

## Discussion

The results showed a clear distinction between the Sequential Group and the Split-Attention Group. All tasks are perceptually based whether sequential or in parallel and consequently test the perceptual limitations. Both modules impose similar working memory loads because they have the same start states, the same intermediate states and the same goal states. The split-attention group, however, requires learners to look at the two parts of the screen and compare them to each other, while the sequential presentation style allowed students to review one problem at a time.

The questions utilized in the pre and post test were similar in operation but not identical. Question 1 had a multiplication operation while question 2 had a division, and question 3 had a power operation. The complexity of the power operation is evident in the presented data and it is the one that led to a cognitive overload.

Consequently the intrinsic load of the operations is not the same and can differ from one operation to another within the same subject. Extraneous load as imposed by the presentation scheme was kept at a minimum by utilizing the Interactive representation approach to student.

## Conclusion

The main conclusion that is evident from these results is that a bottleneck exists somewhere in the perceptual system. It accepts sequential presentation of information and had a problem with the same amount of information being presented in parallel through a split-attention presentation approach. This implies that working memory, although limited, is of a higher capacity than that of the reception bandwidth because if the limit is only to be imposed by working memory then the similar tasks should not result in different behavior. Current technology based education floods learners with unlimited windows that present a large medley of information sources simultaneously. This abundance in parallel presentation may overburden the cognitive bandwidth limit and cause confusion without necessarily reaching the cognitive capacity of working memory.

These results are therefore informative to designers of technology based educational system, in attracting the attention to the simple sequential presentation that is a characteristic of learning from ancient history, to allow learners to build the case they are considering gradually, and then reason about it in memory.

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