



## **Considering cognitive load as a key element in instructional design for developing graphical capability**

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### **Abstract**

Developing skills of graphical capability have been discussed as core competencies in the context of general educational provision by numerous authors in recent years<sup>1,2</sup>. The skills associated with this concept of capability include visuospatial reasoning and problem solving skills. Aligning with contemporary philosophies of educational provision, the flexible development of these skills is of core concern in a dynamically evolving societal context.

Given this focus, the nature of instructional design with relation to educational provision is of paramount importance. Previous research by Delahunty et al.<sup>3</sup> has highlighted possible areas of concern in the application of theoretical graphical knowledge (developed through current educational practice) to applied problem solving activities. Further work has hypothesized the possible underlying variables which may be affecting the problem solving process including transfer issues and conceptualizations of educational tasks<sup>4</sup>.

The conceptualization of tasks is hypothesized to be a core phenomenon in the process of problem solving and must be investigated in the context of task design. However, in the context of designing tasks for learning purposes Sweller et al.<sup>5</sup> discuss cognitive load as a further consideration which is often overlooked. It will be necessary to consider the two areas in parallel and in conjunction with efficacy of task performance in order to gain a deeper understanding of problem solving processes within graphical learning.

The research in this paper, which is part of a larger study currently underway at the University of Limerick, presents an exploration of cognitive load and its relationship to problem solving performance. It takes the form of a critical literature review on the nature of cognitive load and possible effects of graphical task design. Key points within this review are discussed in conjunction with previous exploratory work in the area of conceptualization. The paper concludes by presenting a promising approach to investigating underlying variables affecting problem solving efficacy within a teaching and learning context.

### **Introduction**

The flexible development of a wide variety of cognitive skills lies at the heart of contemporary general educational philosophy. As discussed by McGilchrist<sup>6</sup>, this philosophy involves a reconsideration of cognitive values shifting from the more traditional verbal-analytical to embracing the more holistic-visual aptitudes. This paper focuses on educational research with the latter set of values comprising the principal focus. Visuospatial cognition has been presented as a key set of skills which are critical to a wide variety of human endeavors<sup>2</sup>. These range from simple everyday navigation to technologically advanced surgical research<sup>7</sup>. Given the paramount importance of these skills, their development is a core concern of general educational provision.

Previous research by Delahunty et al.<sup>8</sup> has highlighted the existence of inefficient approaches to current styles of task utilized within current teaching and learning practices. A further study by Delahunty et al.<sup>3</sup> investigated this general issue further within a tertiary context and specifically highlighted deficiencies in student teachers' ability to apply theoretical knowledge to applied problems. Both these studies concluded with the acknowledgement of issues pertaining to surface approaches to problem solving among students but the exact nature of the issues are still

unspecified. These studies took an investigative approach to problem solving strategies and have ultimately lead to the development of a research method centered on the use of electroencephalography to objectively examine cognitive function during performance<sup>4, 9</sup>. It is envisaged that this continuing work on students' problem solving approaches will lead to a deeper understanding of the issues. However, the nature of the problem solving tasks used has not been a core focus within these studies and it is now necessary to consider this.

The conceptualizations of tasks have been discussed as a possible core phenomenon within problem solving and problem based learning particularly in relation to graphical education<sup>4</sup>. However, an often overlooked area with particular relevance to pedagogical task design is that of cognitive load<sup>5</sup>. Cognitive load theory is of critical importance in the design of educational tasks and especially when those pedagogical strategies are utilized under situational constraints such as class periods<sup>10</sup>. The focus of this paper will be primarily concerned with the nature of task design housed in the context of teaching and learning. It will present cognitive load theory as a key factor for consideration in instructional design. The next section will review some of the literature on cognitive load theory and its relationship to learning.

### **Instructional Design for Problem Solving**

Consideration of pedagogical strategy when designing appropriate instructional materials is of critical importance. Due to the applied nature of the philosophy of graphical education in Ireland, the use of strategies centered on problem solving are appropriate and widely used. Much research has shown that the use of such problem-based approaches has significant benefits for the development of flexible and adaptive knowledge and skills<sup>11</sup>. As discussed by Williams et al.<sup>12</sup> the use of problem-based learning (PBL) is synchronous with the overall aims of technology education and helps promote learning. Given the benefits of using PBL as indicated in the literature, the design of problem solving tasks for learning is a key area for consideration.

As alluded to by Delahunty et al.<sup>4</sup>, the conceptualization of tasks is posited to be a critical area of research within this area of PBL. However, another consideration, which is often overlooked in the design of instructional materials, is cognitive load theory (CLT). Sweller et al.<sup>5</sup> outline the three main types of cognitive load as follows:

1. **Intrinsic:** This is imposed by the nature of the information (simple/complex, concrete/abstract) contained within the task or material
2. **Extraneous:** This is imposed by the design of the instructional or learning material and occurs where information irrelevant or unnecessary to the situation is present
3. **Germane:** This is a third category of cognitive load which is directly related to intrinsic cognitive load. It occurs when attention and resources are focused on the intrinsic nature of the learning material utilized and is considered relevant to learning

The type of load that is most relevant in the context of this paper is extraneous load as it is the one that is controlled directly by the design of the problem-solving task<sup>13</sup>. It is crucial to consider extraneous load in the process of designing an instructional task in order to maximize the amount of germane cognitive load which can then result in maximum learning. Extraneous cognitive load becomes an issue when the working memory resources, which have to deal with all types of cognitive load, are exceeded<sup>5</sup>.

It is difficult to completely eliminate all sources of extraneous load in the design of a learning task due to the idiosyncratic nature of the student population. Areas such as learning styles, cognitive style and epistemological orientation effect the manner in which an individual commits resources to a task<sup>14</sup>. In designing a learning task or activity it is important to minimize the amount of

extraneous load so that more mental resources can be allocated to intrinsic and germane load. It is important to note that extraneous load does not always inhibit task performance as long as the working memory resources are not exceeded when intrinsic and extraneous cognitive load are combined<sup>5</sup>. Extraneous cognitive load is the primary type that can be controlled in the instructional design stage and has an inverse function with germane load. In other words, as extraneous load is reduced germane load is increased which promotes higher levels of learning<sup>13</sup>.

The intrinsic nature of the instructional design is determined by the number of elements contained within the material and their associated interactivity<sup>13</sup>. As discussed by Sweller et al.<sup>5</sup>, elements which can be learned in isolation (such as the letters of the alphabet) do not demand a vast amount of mental resources. It is when the elements start interacting that the allocation of resources becomes critical (for example when learning words). As expertise in an area develops, mental schemas are constructed which can combine elements so that they now may be treated as one element in future situations<sup>5</sup>. Therefore, reduction of extraneous cognitive load in the design of problem solving tasks is a core consideration in order to maximize the amount of working memory resources (germane load) which can be allocated to developing these schemas.

Cognitive load can be measured in a variety of ways. Some of the most common are the use of a subjective rating of mental effort<sup>14</sup> and physiological indicators such as heart rate, eye tracking and EEG<sup>15</sup>.

### **Causes of Extraneous Cognitive Load**

There are a number of areas within the design of an instructional task which can contribute to an extraneous load. One of the most common issues is the presentation of irrelevant or unnecessary information within the task or activity<sup>16</sup>. In such a situation, the learner has to allocate resources to processing the redundant information which monopolizes working memory resources. The core implication here in relation to task design for educational purposes is the loss of working memory resources which could have been devoted to the intrinsic nature. This is a clear case where poor task design can lead to an increase in extraneous load which may inhibit learning.

Another area which is closely related to this is the *split-attention* effect which is concerned with the modality in which information, within the task, is presented<sup>5</sup>. It is widely accepted that working memory primarily supports two different modalities. As indicated by Baddeley<sup>17</sup>, these comprise of the *phonological loop* and the *visuospatial sketchpad*. Both deal with primarily verbal and visual data respectively. According to the split attention effect, if one of these channels becomes overloaded, as a result of task presentation, then extraneous cognitive load can be increased<sup>16</sup>. A simple example would be presenting over complex written text and a visual representation which both have to be processed by the visuospatial component of working memory.

Again it is important to note that extraneous cognitive load may not become an issue as long as there are sufficient working memory resources which can be allocated to the task at hand. There are a variety of characteristics within a task which, combined with the introspective characteristics of the learner, can cause a detrimental extraneous cognitive load. It must be acknowledged that not all extraneous cognitive load can be entirely removed however the general optimal approach is to reduce the effects as much as possible while enhancing the capacity to learn from the instructional design<sup>18</sup>.

## The Capacity to Learn

Outlined in the previous section was some of the pertinent literature on the nature of cognitive load, its various types and the complex relationship to learning and instructional task design. It is clear that reducing extraneous cognitive load is of paramount importance when considering or designing pedagogical interventions. This will aid in maximizing the working memory resources which can be focused on the intrinsic nature of the task (increase in germane cognitive load) leading to the development of robust mental schema. So far this paper has been focused on the empirical evidence already developed within the field of cognitive load theory.

Aligning with the perspectives of situated cognition and learning, it is necessary to consider empirical approaches to determining cognitive load effects so that tasks may be enhanced in an adaptive and flexible manner. Embracing the use of such approaches may ultimately enhance educators' task/instructional design and maximize students' capacity to learn from such tasks or activities.

A notable approach that should be considered is that of problem solving efficiency. Hoffman and Schraw<sup>19</sup> discuss the importance of studying problem solving efficiency so that a deeper understanding may be gained of the time and effort required to develop knowledge and skills. This becomes particularly relevant within educational settings as there are often numerous constraints placed on the learning process such as class periods and state examination deadlines. Efficiency within a learning context is broadly defined as *“the ability to reach established learning or instructional goals with a minimal expenditure of time, effort, or cognitive resources”*<sup>19</sup>

Understanding of efficiency within a PBL perspective may allow educators to critically evaluate their instructional designs and subsequently tailor them to student needs. By determining an optimal efficiency within a pedagogical intervention, the affect of extraneous cognitive load will be reduced and germane load will be increased. There are a wide variety of methods utilized to calculate efficiency scores and each has its own set of merits depending on the context of the study in question. It is beyond the scope of this paper to consider these empirical approaches in detail but an extensive review can be found in Hoffman and Schraw<sup>19</sup>.

## General Discussion

This paper has presented a brief overview of the pertinent literature on cognitive load theory and its relationship to learning. Of particular interest in the context of technology education is problem based learning approaches due to the applied nature of the subject area. Focusing specifically on graphical education, previous research by Delahunty et al.<sup>8</sup> and Delahunty et al.<sup>3</sup> has taken distinct approaches to studying apparent deficiencies within current educational practices. These included a focus on the predominant styles of knowledge implemented in the problem solving process and issues of transfer from graphical theoretical to applied tasks respectively. Stemming from this research, a core hypothesis surrounding the relationship between task conception and performance was formed and is currently under investigation<sup>4</sup>. However, during the investigation of these various issues it has become clear that the area of task design for educational purposes is a core concern.

When considering task design, it is apparent that understanding cognitive load in conjunction with the conceptualizations of tasks will lead to a deeper understanding of instructional design. A core issue cited in Delahunty et al.<sup>3</sup> was the use of inefficient approaches to an applied task. The underlying variables influencing these approaches still remain tentative but it is possible that a high cognitive load inhibited students' conception of the task which forced the adoption of sub-optimal strategies to deal with the situational demands. The relationship between conception and cognitive

load is not well understood and could be a converse effect. In other words the conception of the task could be determining some of the cognitive load present in the solving of the task. High levels of cognitive load have been shown to lead to a reliance on the use of inefficient strategies when dealing with applied problems or tasks<sup>5</sup>.

This relationship between conceptualization and cognitive load seems plausible when one considers the theory of *entrenched* conceptualizations<sup>20</sup>. This refers to the automaticity at which some of our cognitive functions may be recognized and executed after a sustained period of practice and is a particularly useful trait in everyday practical situations<sup>20</sup>. However, this may become a negative phenomenon in an educational setting when the goal is to develop adaptive and flexible problem solving skills. If tasks are constantly conceptualized in a specific manner (entrenchment) then there will be occasions when the cognitive load will be high and the subsequently adopted strategy will be sub-optimal. An inhibition of learning may then occur due to the extraneous nature of the cognitive load induced by that conception of the task. This theoretical relationship seems plausible when considering that the efficiency of processing within working memory is dependent on task complexity (e.g. conception) and demands (e.g. cognitive load)<sup>21</sup>

As discussed, adopting an efficiency perspective within the instructional design stage may lead to a better understanding of conditions which can maximize the effect of the pedagogical design. This perspective provides a practical approach which can be used to examine the suitability of instructional interventions. As already discussed, there is evidence<sup>3, 8</sup> which may suggest the unsuitability of current task designs for developing graphical capability. Taking some of the perspectives from CLT and the efficiency literature it is now possible to evaluate task design practices so that a deeper understanding of instructional interventions may be gained.

In conclusion, it can be seen from the brief review of literature surrounding cognitive load theory that there are a number of important considerations which must be acknowledged in developing graphical tasks. Evidence exists to suggest deficiencies in the current state of teaching and learning within graphical education. A deeper understanding of the effects of cognitive load in conjunction with task conception should aid in highlighting some of the underlying variables of causation.

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