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An enquiry into the use of interactive concept maps in mathematics

DISSERTATION

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I hereby certify that this material, which I now submit for assessment of the programme of study leading to the award of Master of Science in Learning Technologies is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Introduction

The aim of this research paper is to examine the use of multimedia concept maps as a means to developing self-regulated learning (SLR) practices among students. SRL is a fundamental element of Lifelong Learning, a term which is used consistently in discussions about globalisation, knowledge economies and as a necessity for concerned, informed citizenship in the 21st century.

SRL is facilitated best in a constructivist approach to lesson delivery which involves the student becoming active participants in learning where new ideas are incorporated into existing understanding. The use of ICT can augment constructivist based learning especially in the context of learning mathematics. As there are very few educational software programmes that are made specifically for the Irish mathematics curriculum, a study to see if the use of a content free concept mapping software and the provision of short, multimedia instructional 'chunks' of algebra encourages in the integration of ICT into the curriculum is examined.

The literature review provides an insight into the latest research findings in the cognitive sciences that control our ability to learn; memory, recall after learning, learning to learn and assimilation theory. Based on these findings, a correlating review of the use of concept mapping is discussed leading to the argument for incorporating multimedia as an additional dimension to concept maps. Higher order thinking skills and the ability mathematisise are reviewed in the context of current trends concerning mathematics teaching. These trends are then cross referenced to current teaching practices to see how the use of multimedia concepts maps could be employed to develop effective strategies for problem solving.

Following the hypothesis and research question, the method employed for this research is detailed. The method section presents the background to the sample chosen, the development of the multimedia algebra elements and the instruction that was given to the pupils and the class teacher. The following sections of the dissertation are; an analysis of the qualitative survey results; a discussion of the key findings and conclusions; and finally suggestions for further research and direction in the field.

Executive Summary

Concept Maps have been credited as mechanisms that sponsor meaningful learning. They represent an external visualisation of knowledge. In response to a focus question, the development of a Concept Map creates an exploratory approach to the problem which in turn creates a learner centred environment that develops higher order thinking skills and critical thinking strategies

Converse to the *creation* of an external visual of knowledge, the use of multimedia in ICT *presents* the learner with a visual learning environment. Typically, this has the effect of presenting knowledge in a format that is motivating, easier to understand and is of particular use to learners trying to understand abstract concepts.

As abstract concepts are a common feature of mathematics curricula, this study is an examination of the effects that a coordinated combination of small instructional video units of algebra in a concept mapping software would have on students. As the use of ICT in schools faces many challenges and obstacles, the study examines the potential for integrating ICT in a more meaningful way into curriculum teaching. The study comprises three components; a post-tuition evaluation of pupils ability to concept map using software, teacher interview examining effects of the project on workload and class management issues and finally an qualitative survey to evaluate pupils ability to create multimedia concept maps in a self-regulated learning environment.

The principle finding was an increase on teacher workload which acted negatively on expanding the study beyond the pilot phase. Preparation of lesson material for constructivist teaching was more time consuming and seemed to produce little more in terms of pupils progression in the subject. This may be due to the relatively short period of the experiment. Although pupils were comfortable with the use of the computer, considerable instruction was required to enable them use the mapping software to a competent level. However, the pupils were more engaged and demonstrated a positive disposition to problem solving in a collaborative environment.

1. Literature Review

This dissertation is an examination of the use of Concept Maps in education. It focuses on using Concept Maps to develop higher order thinking skills and how these skills are required to apply learning strategies in unfamiliar contexts. While concept Maps are used in many environments, the literature review was concentrated on research pertaining to their educational use and how they reflect the findings of research into many aspects of learning theory.

The human mind is limited in the amount of information that it can process (Miller, 1956). Studies show that on average we can only process seven plus or minus two units of information at the one-time. To understand the factors governing these limitations a review of literature in the area of cognitive science was undertaken.

The discipline of cognitive science deals with the mental processes of learning, memory, and problem-solving (Cooper, 1998). The theories reviewed in this section include the following: dual coding theory, schema theory, and cognitive load theory. For the purposes of this dissertation, these theories are used to examine how information is processed, how learning occurs and the relevance these theories have on the use of concept mapping as an instructional strategy.

Dual coding theory

Paivio (1986) is given credit for developing the dual coding theory which proposes that working memory (commonly referred to as short-term memory) is comprised of several separate but interrelated systems for passing information. He states "human cognition is unique in that it has become specialised for dealing simultaneously with language and with non-verbal objects and events" (p. 53). Baddeley (1986, 1999) proposed that there was a component in working memory that controlled subcomponents or slave systems. This core system, called the central executive, is responsible for controlling the overall system and engaging in problem-solving tasks and focusing attention. Baddeley asserts that the central executive could transfer storage tasks to two slave systems in working memory, so that the central executive could continue to have capacity to perform more processing tasks.

The two slave systems of working memory are referred to as the visuo-spatial sketchpad and phonological loop. Some scholars referred to these systems in simpler terms as linguistic and imagery (Marzano *et al.,* 2001). Even though they can be activated independently, there are connections between the systems that allow for at the dual coding of information. The verbal System specialises in processing and storing linguistic information such as words and sentences, which are represented as logogens (elements of the verbal system) when they are stored in memory. The visual system processes images when they are represented as imagens (elements of the imaging system) in memory (Wang, 1994).

Other principles of dual coding theory and instrumental in understanding the implications the theory has for learning, and particularly for the use of concept maps. The processing of verbal and/or visual information can occur on three different levels. Representational processing refers to the activation of verbal and non-verbal representations, depending on the corresponding type of stimuli. Referential processing is the activation of the verbal system by the non-verbal system or vice versa. Associate processing is the activation of representations within either system (Sweller, 2003).

Saavedra (1999), in her paper reviewing dual coding theory, states that proponents of the theory believe that dual coded information is much easier to retain and retrieve because of the availability of two mental representations (verbal and visual) instead of one. Also, the processing of images is more likely to activate both coding systems than are words alone. The more we use both forms, the better we're able to think about and recall information (Marzano *et al.,* 2001). The theoretical underpinnings of dual coding theory have implications for the use and value of concept maps for instruction. Concept maps are important in the processing and storing of information so that it can be retrieved free use at a later time. Marzano asserts that a concept maps "enhance the development of nonlinguistic representations in students, and therefore, enhance the development of that content" (p. 73) the use of concept maps also helps student generate linguistic representations. As visual learning tools, they can help learners process non-verbal information; and since they tend to be predominantly text-based, they have an added advantage of helping learners process verbal information as well.

Schema Theory

According to schema theory, the memory is composed of a network of schemas. Doyle (1999) describes the scheme as "skeletal frameworks containing categories for specific information....Existing schema and the information contained within our known as prior knowledge." Even though many descriptions of schemas exist, Winn and Snyder (1996) stated that all descriptions include the following characteristics:

- A schema is an organised structure that is part of our memory. Combined with all other schemas, it contains the sum of an individual's knowledge.
- The schema can be understood as a network of concepts connected by links. Schema consists of nodes and links that describe the relations between the node appears.
- Schema are formed through generalities or abstractions as opposed to a specificity of information. For example when we look at the cat, we observe many features such as size, colour, breed etc. the schema that we have constructed from experience to represent "cat" in our memory does not contain all these details. Our "cat" schema would tell us that it has eyes, four legs, and raised ears.
- Schemas are dynamic structures. As new information is learned it is, to use Piaget's terms, assimilated and accommodated into existing schemas or used in the formation of new schemas.
- The schemas provide a context that affects how the new experiences are interpreted. For example, when reading material with which one is not familiar, the information will be interpreted based on existing schemas.

According to Dye (2000), "concept maps have their roots in schema theory". Linking the new information to existing knowledge is one way that teachers can help students learn new information to help students make these links teachers need to present material in ways that facilitate such landing concept maps can help students link their existing knowledge to new knowledge and help them build the scheme and the need to understand concepts, according to research conducted by Guastello (2000).) In other words, as learning occurs, increasingly sophisticated schemas are developed and learned procedures are transferred from controlled to automated processing. Automation, frees capacity in the working memory for other processing functions.

Schema theory emphasises the importance of activating prior knowledge when teaching. If prior knowledge is activated, the schema will provide a framework on which the new knowledge can be attached and, consequently, comprehension would be improved. The implication is that graphic organisers can facilitate this learning (Doyle, 1999; Robinson, 1998). When used as an advance organiser, giving an overview, concept maps can improve student achievement (Willerman & MacHarg, 1991) Furthermore, research on the abilities of a novice versus expert performance (Chi et al., 1988) suggests that the nature of expertise is largely due to the possession of schemas that guide perception and problem solving. An expert in a particular area will have much more expansive schema than that of the novice and will also have a high level of automation to perform tasks without concentrating (Wilson & Cole, 1996).

Cognitive load theory

Cognitive load is the amount of mental resources necessary for information processing (Adcock, 2000). Cognitive load theory maintains that working memory can deal with a limited amount of information. The limitations of working memory are bound by the types of schema a learner has or by the learner's prior knowledge.

According to several researchers, implications from the theories of the cognitive load can be applied to lesson planning (Cooper, 1998; Wilson & Cole, 1996;). These researchers believe that visual learning tools such as concept maps can reduce the cognitive load (i.e., the number of items to be attended to and processed by working memory). However, understanding cognitive load theory and, in turn, its implications for concept mapping, requires the description of several key principles. Cognitive load theory maintains that working memory can deal with only a limited amount of information and if that capacity is exceeded, the information is likely to be lost.

Working memory has a threshold of anywhere between four and 10 chunks. The definition of a chunk depends on the schemas of the individual learning the information. It depends on the schema of the learner because, generally, chunks are schemas (Cooper, 1998). This leads to a brief definition of schema and schema theory. Dunston (1992) states that schema refers to how knowledge of concepts is organised and stored in memory. A schema is a skeletal framework containing categories, or slots, for specific information. The quantity, quality, and boundaries of the categories within the schema are, the most part, determined by personal experiences.

Therefore, the limitations of working memory are bound by the types of schemas the learner has, or in other words, the prior knowledge possessed. An expert in a particular area will have expansive schemas, or information networks, with a high level of automation, or ability to perform tasks without concentrating (Wilson & Cole, 1996). Another principle that applies is the interactivity between chunks of information which are referred to as elements by Cooper (1998). Some information can be difficult to learn because there is a need to attend to the relationships between elements. Schemas, as information networks, provide the ability to combine many elements into a single element and the capacity to incorporate the interactions between elements (Cooper 1998). According to Cooper (1998), "cognitive load refers to the total amount of mental activity imposed on working memory as an instance in time. The major factor that contributed to cognitive load is the number of elements that need to be attended to." (p. 10). Consequently, for a novice learner who doesn't have the schemas of an expert, the information to be learned will have a higher cognitive load than for an expert. The novice will not be able to process the same number of elements or the same number of interactive elements as an expert who has previously acquired schemas.

There are three other relevant concepts within cognitive load theory. Intrinsic cognitive load refers to the difficulty of the content to be learned. This applies to content which cannot be modified or simplified. Some content is going to be difficult to learn no matter how it is presented. Extraneous cognitive load refers to how much demand is placed on working memory to learn the new material (Cooper, 1998). This is often caused by factors that aren't central to the material to be learned, such as presentation methods or activities that split attention between multiple sources of information, and these should be minimised as much as possible. Germane cognitive load, enhances learning and results in task resources being devoted to schema acquisition and automation (Sweller, Van Merrienboer and Paas, 1998). Intrinsic, extraneous, and germane cognitive loads form an equation in which the sum total of the three cannot exceed working memory resources for learning to occur (Paas, Renkl, & Sweller, 2003).

The level of extraneous cognitive load can be modified to facilitate student learning. In other words learning some content may be easier for students if the extraneous cognitive load is lessened by changing or modifying how the material is presented. Chandler and Sweller, (1991) demonstrated that one method of reducing extraneous cognitive load is to eliminate redundant text. Mousavi, Low and Sweller (1995) and Sweller *et al.,* (1998), argued that cognitive load is reduced by the use of dual mode (visual-auditory) instructional techniques and that the limited capacity of working memory is increased if information is processed using both the visual and auditory channels, based on Baddeley's model of working memory.

These aspects of cognitive science are of particular importance to the design of lesson plans. Based on the research on cognitive load theory, changes to the way new material to be learned is presented can have significant effect on learning outcomes if cognitive load could be reduced. The lesson design would have to take into consideration the presentation of materials into 'chunks' (Miller, 1956) that are needed to learn or perform the educational objective. The lesson plan would have to ensure that the learners had sufficient automation of tasks before trying to tackle an overall task that might be beyond the learners capability. There are similarities here to Vygotsky's *Zone of Proximal Development* and Piaget's concept of *Scaffolding*

Following the theories outlined above, Sweller *et al.,* (1998) proposed several instructional design techniques based on cognitive load theory. These instructional principles are identified as the goal- free effect, worked example effect, completion problem effect, split-attention effect, modality effects, redundancy effect and the variability effect.

The goal-free effect suggests that problems should not be given an end-goal, because it causes the learner to have to maintain several conditions in working memory while they engage in problem solving. The goal-free problem reduces extraneous cognitive load and aids in schema construction. One example is a conventional geometry problem would require the learner to find a value for a particular angle, while goal-free problems ask students to find the values of as many angles as they can.

The worked example effect states that providing learners with worked out examples of problems to study can be just as or even more effective in building schemas and performance transfer than having to work out similar problems themselves. This means that if a multimedia instructional unit was appealing enough to hold the learner's attention and cause the learner to really study the process of the worked out problem in detail then it could likely be just as much or more effective than having them work the problem at themselves, at least initially.

The critical factor in learning from worked examples is that the examples must be carefully studied. However many learners don't do this, instead they use the worked example as a template. A way around this is to offer the students problems which provide a goal state and a partial solution and have the students complete the partial solution. This type of activity combines the positive aspects of worked examples of a problem as the learner must critically examine the partially worked example and then apply what they have learned.

Split-attention occurs as when learners are presented with multiple sources of information that have to be integrated before they can be understood. A typical example of this effect is found in many textbooks where illustrations of a topic to be learned are separated from their explanation in text. This has a negative affect on learning as the learner has to concentrate their attention on two separated sources of information.

Modality effect draws on Baddeley's (1986) theory of visual and auditory working memory subcomponents. Effective working memory capacity can be increased by using auditory and visual working memory together rather than using one or the other alone. The information that is directed at each "memory channel" should be such that it cannot be understood in isolation, but needs to be integrated with information in the other channel to be fully understood. This effect relates directly to the potency of multimedia instruction when information is presented visually with a supporting narrative.

The redundancy effect occurs when information that can be fully understood in isolation, as either visual or auditory information, is presented to both channels as essentially the same information. Challenging both memories to integrate the same information has the effect of increasing cognitive load.

The variability effect is a technique that recommends the variability of practice because it encourages the learner to develop schemas that aid in transfer of knowledge to similar situations. The more variability, the more the learner will develop multiple schemas than allow them to recognise common components under different conditions and apply what they have learned to solve problems in other areas.

Concept Maps

Concept maps are diagrams that represent organised knowledge (Novak & Gowin, 1984). They are graphical representations of knowledge comprising concepts and the relationships between them. A concept is defined as a perceived regularity in events or objects, designated by a label. The label for most concepts is a single word, although sometimes symbols can be used as + or %. Concept are usually enclosed in circles or boxes, and relationships between concepts are indicated by connecting lines that link them together. Words on the linking lines specify the relationship between the concepts. The concept-linking line-concept unit forms propositions, which are meaningful statements about the object or event. These are often referred to in literature as semantic units or units of meaning.

The typical characteristic of concept maps is that the concepts are represented in a hierarchical fashion with the most inclusive, most general concept at the top of the map and the more specific, less general concepts arranged below. The concept map may pertain to some situation or events that we are trying to understand through the organisation of relevant knowledge, thus providing the context of the concept map.

An important characteristic of concept maps is the inclusion of "cross links". These make explicit the existence of relationships between concepts in different regions of the concept map.

Concept maps were developed in the course of Novak's research programme in which he sought to follow and understand changes in children's knowledge of science. Novak's work was based on the learning psychology of Ausubel (1968). The fundamental idea in Ausubel's cognitive psychology is that "learning takes place by the assimilation of new concepts and propositions into existing concept and proposition frameworks held by the learner".

One of the fundamental goals in the use of concept maps in this context is to develop meaningful learning. Ausubel drew a distinction between rote learning and meaningful learning and stated that meaningful learning requires three elements:

- New material to be learned must be conceptually clear and be relatable to the learner's prior knowledge.

- The learner must possess relevant prior knowledge. Generally, the school-going child has some knowledge of practically any domain but it is important to be explicit in building concept frameworks when wishing to present more details specific knowledge in later instruction

- The learner must be willing to learn meaningfully. As learning is idiosyncratic the learner must attempt to incorporate new concepts and new meanings into their prior knowledge rather than just memorising definitions or propositions or from that matter computation of procedures. (Ausubel 1964, 1968)

Mayer and Moreno (2003) describe meaningful learning as deep understanding of the material, which includes attending to salient aspects of the presented material, retaining relevant information in both visual working memory and auditory working memory, organising it into a coherent mental structure and integrating it with relevant prior knowledge. Meaningful learning is demonstrated when the learner can apply what is presented in new situations, and students perform better on problem-solving tests when they learn with words and pictures (Mayer, 2001). Two important ways to promote meaningful learning is to design activities that reduce cognitive load, which frees working memory capacity for deep cognitive processing during learning, and to increase the learner's interest, which encourages the learner to use this free capacity for deep processing during learning. Concept maps are helpful in meeting these conditions by identifying general concepts prior to instruction in more specific concepts, and by assisting the sequencing of learning tasks through progressively more explicit knowledge that can be anchored into developing contextual frameworks.

Another powerful use of concept maps is as an evaluation tool when used to encourage students to seek meaningful learning patterns (Novak & Gowin, 1984; Novak, 1998; Mintzes, Wandersee & Novak, 2000). Concept maps are also effective in identifying both valid and invalid ideas held by students. They can be used effectively to identify the relevant knowledge and learner possesses before or after instruction (Edwards & Frazer, 1983). Mayer (2001) lists the cognitive processes that contribute to meaningful learning from multimedia: selecting words, selecting images, organising words, organising images, and integrating.

Concept maps demonstrate a relationship between the psychology of learning and the consensus that new knowledge creation is a constructive process involving both our existing knowledge and our drive to create new meanings and new ways to represent these meanings. In the creation of a concept map, students are engaged in a creative process, and this can be challenging to many, especially to those who have spent most of their lives learning by rote. Rote learning contributes very little to our knowledge structures, and therefore cannot underlie creative thinking and novel problem-solving. Concept mapping is an exercise in critical thinking and the identification of new problem-solving methods (Novak & Gowin, 1984).

Critical thinking skills are often defined as the ability to identify cause-effect relationships; make predictions; draw inferences; and analyse, synthesise, or evaluate information. These are the typical constructs which correspond to the upper levels of thinking on Bloom's taxonomy. The process of developing and using concept maps has been shown to enhance students' critical thinking or higher order of thinking skills (Brookbank *et al.*, 1999; DeWispeleare & Kossack, 1996). In addition to developing critical thinking skills, concept maps have also been shown to help students with mathematical problem-solving (Braselton & Decker, 1994). Further studies by Bos & Anders, 1992; Richie & Volkl, 2000; Griffin *et al.*, 1995; demonstrates that students have effectively used concept maps to increase their capacity to retain and recall information.

Collaboration

Concept Maps are constructed to represent an individual's knowledge and understanding of a topic. They can also have a strong influence when constructed as part of a collaborative group process. It facilitates the exchange of ideas and information following the presentation of a focus question. Collaborative concept mapping establishes an inclusive environment, accommodates the different viewpoints of the collaborators which encourages participation and negotiation for meaning through clarification and reiteration. Collaborative creation of a concept map can be synchronous with the whole group working concurrently, or asynchronously where different collaborators work on different areas of the concept map either by adding to the hierarchy, defining or redefining the relationships.

Some benefits of collaboration in concept mapping are evident in a study by Esiobu & Soyibo (1995). In this study small groups of students used concept maps at the end of classroom instruction to summarise the lesson. A control group who did not use concept maps did not perform as well as the treatment group following an end of term multiple-choice question achievement test. In another study, Roth and Roychodury (1993) used concept maps successfully to examine the quality of student understanding. However since collaboratively working on hypervideo might include some potential disadvantages, as it may be too demanding for learners in some cases (Zahn *et al.*, 2002). To this end, specific instructional videos were created for the experiment in hypervideo concept mapping which is discussed later in this paper.

However, there is some research that indicates that there is no benefit for a collaboration in the production of Concept Maps. Herl, O'Neill, Chung & Schachter (1999) researched the use of Concept Maps between two groups of students. One group worked collaboratively over a network to construct a group map while the other group worked individually constructing maps using information from Web searches. Over the course of the year, students engaged in the creation of individual maps showed significant improvement in mapping scores. Students in the collaboration condition did not show any change. However, the nature of the interaction between participants would appear to have an influence on whether or not collaboration has a positive effect. (Chinn, O'Donnell, & Jinks, 2000). Collaborative Concept Mapping has the effect of promoting more debate, questioning, discussion and reasoning in student interaction and results in a more dense conceptual representation. Stoyanova & Kommers (2002).

Types of Maps

There are many types of mapping systems, for example knowledge maps, conceptual graphs, and mind maps. Concept maps differ from the others because of their foundation in Ausubel's assimilation theory of learning. Also because there is no constraint on the nature of linking phrases in the construction of semantic units of information. Beginning a concept map usually involves defining the focus question, then identifying and listing the most important general concepts associated with that topic and then ordering the concepts from top to bottom on the map and adding labels and linking phrases. Once the basic concept map has been built, it can be reviewed for its completeness and accuracy; followed by an exploration of the maps different knowledge domains in an attempt to establish (creative thinking) cross links. There is evidence that learning is enhanced during concept mapping when learners adopt an active, questioning approach to the subject matter. Such active, engaging, transformation or interaction with many types of materials has been suggested to enhance learning in general (Feltovich, Spiro, & Coulson 1993). While other activities like outlining or defining concepts can assist the learner in taking a systematic engaging and thoughtful approach to the topic, concept mapping is superior to all other interventions as it assists the learner in recognising the relationship between concepts and between knowledge domains. (Horton *et al.,* 1993)

Application

There are many educational applications of concept mapping. It can be used as a scaffold of understanding, to consolidate educational experiences, improving the effective conditions from learning, as an alternative to traditional writing assignments, a tool to teach critical thinking and as an aid to the process of learning by teaching. Concept mapping has been used to identify students current understandings and misconceptions and a formal assessment tool. They also have benefits as advance organisers and navigation aids within subject topics. There is further evidence that the use of concept maps in educational settings encourages the learner to interact with the subject material promoting active inquiry and organisations by asking for explanation, seeking justification defining connection amongst the other elements of the concept map and so further developing the learner's continued questioning about the new subject material. A well constructed concept map can also assist learners in finding connected information more quickly. Organizational characteristics of a concept map including colour coding, emphasis and animation offering additional 'memory hooks' to assist in the retention of information.

From the many publications of the various uses of concept maps it would appear that the most prevalent use of concept mapping is for teaching and learning. Concept maps help to externalise current understanding of the subject and equally misconceptions held by the learner. Identification of existing understanding and any misconceptions provides a platform to develop constructivist approaches to teaching and pursuit of shared, meaningful understanding between instructor and learner. Kinchine, Hay and Adams (2000) also suggest that the use of concept maps from quality of assessment of student learning is more appropriate than quantities of examination methods when the intention is formative assessment of student understanding.

Assessing Concept Maps

The standard method of scoring a concept map by Novak and Gowin (1984) is based on scoring the structure of the concept map; they suggest five points for each level of the hierarchy, the number of branches with an award of 1 point for each branch, 1 point three to valid proposition and a high-scoring 10 points to each valid crosslink (domain to domain). Cross links achieved the highest score as they demonstrate the degree of integration of meaningful understanding. The hierarchical levels addressed the degree of subsumption and the branchings indicate progressive differentiation. While it can be time-consuming to score a concept map in this manner, it does clearly demonstrate the learner's understanding and knowledge structure in this domain. There have been some additional developmental extensions of this scoring technique with adjustments made to the weighting of the scoring system. Shaka & Bitner (1996) suggest a simplified method of scoring the concept map by giving most of the components of the map a rating from zero to four rather than counting or attempting to characterise the condition of each component.

Another method of using concept maps for evaluation is proposed by Ruiz-Primo & Shavelson (1996) where the maps of a novice and expert are compared. Expert concept maps are produced by teachers or subject matter experts and comparisons (under agreed boundaries) are performed examining propositions and the overall structure of the expert and novice concept maps. In an effort to reduce the time required to judge the validity of propositions and concept map construction, researchers at Centre for Research on Evaluation Standards and Student Testing in the U.S. are developing automated scoring systems. However, structural and holistic comparisons still require human judgment as they are very difficult to automate.

In a research by McClure, Sonak & Suen, (1999) a measure of validity and reliability between different scoring methods, holistic assessments, correctness of propositions and a degree in which the people scoring the maps agreed with the internal reliability of the measure were evaluated. The validity of map scores was assessed by comparing student constructed maps with expert maps. A high proportion of concept map scoring techniques resulted in significant correlations between student maps and master maps. The best technique, both in terms of inter-rater reliability and validity was based on propositional analysis of the concept map. Construct validity, has been more difficult to establish as the measure refers to the extent to which concept maps compared with other measures of meaningful learning. There are some suggestions that concept maps measured different aspects of knowledge than traditional assessment which does not measure a meaningful learning. This, along with the notion that concept maps measure conceptual changes of understanding, most likely explains the low correlations demonstrated in research between concept mapping and the more traditional types of assessment (Novak, Gowin & Johansen, 1983).

Advance Organisers

When used as advance organisers, providing aerial overview of the subject to be learned, concept maps can be used to foster meaningful learning in two specific ways: by prompting the learner of their existing superordinate cognitive concept structure and by providing a context for the general concepts into which the student can incorporate progressively differentiated details (Ausubel, 1968). As teaching tools, advance organisers are most efficient when they make explicit the relationships between learned concepts that the learner already knows, which in turn provides a structure upon which new concepts can be categorised and integrated. A concept map, constructed to be an advance organiser by a classroom teacher and presented at the beginning of a class, can assist students by representing the topics of the lesson, the sequence in terms of pre-requisite relationships, and any additional explanatory information required may be incorporated into the map where used as an organizational tool. Novak (1998) suggests that using a concept map as an advance organiser for curricular planning on a specific topic can help to make the instruction "conceptually transparent" to students.

The use of concept maps for navigation can help people locate pertinent information quicker and more easily. As a result, academic researchers have expressed an interest in the use of concept maps as *knowledge hypermaps.* While there is no clear evidence of an improvement in the ability to recall key information acquired through the use of a hyperlinked knowledge map, students reported that the use of hypermaps were helpful in studying and learning (Hall, Balestra and Davis, 2000). It would appear that simply presenting structural information is only part of the process required to achieve meaningful learning. Participants have to be encouraged to actively process the information they are viewing and to think in terms of meaningful relationships.

Concept Maps and Hypervideo

The purpose of concept maps is to visually represent knowledge of the subject or domain. Jonassen (1992) refers to concept maps is accurate reflections of their authors' cognitive structures. This argument has been based on concept maps that portray text-based propositions only. He questions the effectiveness of concept mapping where concepts are portrayed only through verbal means. To be a true externalisation of the cognitive structure held by the learner in a particular knowledge domain, the nodes of the concept map should facilitate other forms of knowledge expression.

"It is important to note that not all nodes in a semantic memory system have names corresponding to words in natural language" (Rumelhart and Norman 1985 p. 24). This notion is further supported by numerous researchers who have offered evidence or arguments from the notion that one's knowledge contains more than simply verbal propositional knowledge. Kosslyn (1980) proposes a cognitive model that represent information about objects with both propositional properties and images. Similarly, mental models of a knowledge domain include both propositions and imagery which also provides evidence that memory from visual imagery is more robust than that for purely textual information. And, as previously discussed, Paivio (1986) asserts information encoded both visually and verbally is more memorable. Therefore, there is strong argument for the inclusion of imagery in concept maps.

The design of concept maps as suggested by Novak refers to producing two dimensional concept maps which integrates concepts in a geometric shape with a label and annotated lines connected to related concepts. As multimedia technologies were not as available as they are today, concept maps of the 1960s were only ever considered to be as two-dimensional maps. In our previous example of the concept of a cat, a four-legged creature with upright ears, reproduces a static mental image. Instinctively, we also possess temporally dynamic visual and auditory associations with this concept which form an integral part of our knowledge about this object or domain. One's knowledge of cats will not only include was a cat looks like, but what cats looks like when they are running, jumping, pouncing, etc. The incorporation of temporally dynamic visual and aural elements – hypervideo - in a concept map enhance its "flexibility of expressiveness" (Heeren & Kommers, 1992). This may help to accommodate students with different expressive or learning preferences when using concept maps to demonstrate their own knowledge or acquire new knowledge. These students will be presented with; what objects look like when in motion, what they sound like and there is the potential to present instructional visualisation is of how to perform procedural tasks. It is suggested that the use of hypervideo in an interactive concept map may provide a more engaging user experience creating a motivational effect on the learner (Vroom, 1994).

Learning with hypervideo in concept maps

In addition to the various cognitive modes that facilitate learning as previously discussed there are all so different phases in the learning process. In a learner centred pedagogical model, there are three phases: conceptualisation of the subject and its domain; construction, where the learner actively engages with the subject while relating to their own knowledge framework; and dialogue, where the learner expresses aspects of the emerging understanding and relates this to the understandings of fellow learners and teachers. There are also learning styles or cognitive preferences that determine the most effective method of learning for the learner. Learning styles and based on the premise that individuals perceive, organise and process information differently. Examples of these theories include the VAK perceptual learning styles: visual, auditory, kinaesthetic; and Kolb's learning styles, reflector, pragmatist, theorist, and activist. This differentiation of learning styles suggests a need for a flexible support. In an ideal learning environment would have the flexibility to support or learning styles and allow each learner to spend more time on their preferred style while inducing the development of skills in their non-dominant learning style.

Empirical evidence shows that video materials can foster learning by visualising dynamic processes, which might not be observable in reality or which are hard to describe verbally and by combining pictures, text and narration into coherent media messages (Mayer, 2001). Constructivist viewpoints further support this evidence and consider interactive video as an effective support for experience-based learning and situated learning. In a study by Guimares *et al.*, (2000), students who worked collaboratively creating a video based hypermedium were very motivated by their task and appreciated the freedom to integrate different media especially video clips into hypermedia structures. A further study of this type reveals that individual learners used hypervideo structures in flexible ways according to their own learning strategies, and were thereby very successful in acquiring new knowledge (Zahn, Schwan and Barquero, 2004).

So far in this literature review we have examined learning and learning styles as they relate to research into cognitive science, learning to learn, concept mapping and the argument for the use of hypervideo within cognitively mapped structures. Use of these technologies and methodologies demand a learner centred environment. As teachers become facilitators of inquiry and offer guided instruction, students will take control of their learning to become lifelong learners.

Although commonly referred to in a generic sense, lifelong learning is described as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation and behaviour guided and constrained by their goals and a contextual features in the environment" (Pintrich 2000, p. 453). In this context, lifelong learning refers to the individual taking control over their learning environment to become self-regulated learners. Zimmerman (2000) refers to self-regulation as "self-generated thoughts and behaviours" that are orientated towards attaining goals and a "major function of education in the development of lifelong learning skills".

Some key, self-regulatory processes are defined by Schunk & Zimmerman (1998) that link to a learners ability to learn in this manner. Selective and adaptive use of these processes must be applied to each learning task. The component skills include;

- Setting specific proximal goals for oneself,
- Adopting powerful strategies for attaining the goals,
- Monitoring one's performance selectively for signs of progress,
- Restructuring one's physical and social context to make it compatible with one's goals,
- Managing one's time use efficiently,
- Self-evaluating one's methods,

- Attributing causation to results, and
- Adapting future methods.

To become lifelong learners, one must become familiar with certain strategies for learning which will identify potential learning situations and invoke methodologies to harness the knowledge potential. Such methodologies as described by Zimmerman (2000) are in the terms of learners becoming Self-Regulated Learners.

Self Regulated Learners

Self-Regulated Learning (SRL) emphasises the responsibility of students to take charge of their own learning. SLR incorporates research on cognitive strategies, metacognition, and motivation into a construct that emphasises the interplay between these forces. It emphasises that the "self" is the agent in establishing learning goals and tactics and how each individual's perceptions of the self and task influenced the quality of learning that ensued. (Paris & Byrnes, 1989).

SRL can help describe the ways that people approach problems, apply strategies, monitor their performance, and interpret the outcomes of their efforts. There are three central characteristics of SRL; awareness of thinking, use of strategies, and sustained motivation.

Awareness of thinking. Part of becoming self-regulated involves awareness of effective thinking and analysis of one's own thinking habits. This is metacognition, or thinking about thinking (Flavell 1978). Flavel's research showed that children from 5-16 years of age become increasingly aware of their own personal knowledge states, the characteristics of tasks that influence learning, and their own strategies for monitoring learning. Paris *et al.*, (1989) summarized these aspects of metacognition as children's developing competencies for self-appraisal and self-management and discussed how these aspects of knowledge can help direct students' efforts as they learn.

Bandura (1986) asserts that self-regulation involves three interrelated processes; self-observation, self-evaluation, and self-reaction. Understanding these processes and using them deliberately is the metacognitive part of SRL. The educational goal is not simply to make pupils think about their own thinking but, instead, to use metacognitive knowledge to guide the plans they make, the strategies they select, and the interpretations of their performance so that awareness leads to effective problem-solving.

Use of strategies. A second part of SRL involves a person's growing repertoire of strategies for learning, studying, controlling emotions, and pursuing goals. An important distinction here is "being strategic" rather than "having" a strategy. It is one thing to know what a strategy is but it's quite a different thing to be inclined to use it. There are three important metacognitive aspects of strategies, often referred to as declarative knowledge (what the strategy is), procedural knowledge (how the strategy operates), and conditional knowledge (when and why a strategy should be applied) (Paris, Lipson, & Wixson, 1983). Knowing these characteristics of strategies can help students to discriminate productive from counterproductive tactics and then to apply appropriate strategies. When students are strategic, they consider options before choosing tactics to solve problems and then they invest effort in using the strategy. These choices embody SRL because they are the result of cognitive analyses of alternative routes to problem-solving.

Sustained motivation. The third aspect of SRL is motivation because learning requires effort and choices. Paris *et al.*, (1983) argued that ordinary learning fuses skill and will together in self-directed actions. SRL involves motivational decisions about the goal of an activity, the perceived difficulty and value of the task, the self-perceptions of the learner's ability to accomplish the task, and the potential benefit of success or liability of failure. Awareness and reflection can lead to a variety of actions depending on the motivation of the person.

Self-regulated learning does not mean that knowledge and learning exists solely in the mind of an individual. Rather, self-regulated learning recognizes that individuals have some control over their own learning, across contexts, across relationships, and across situations.

SRL and Mathematics

Mathematics curriculum designers aim to develop materials that foster skills such as learning to reason statistically, to think algebraically, to visualise, to solve and pose problems. Internationally, there is a move towards mathematics education that emphasises conceptual understanding, strategic confidence, adaptive reasoning, and procedural fluency (Kilpatrick et al., 2001). However, in practice designing classroom environments and teaching pedagogies that promote these principles has proven difficult. Developing mathematics students who actively engage in strategic behaviours and regulate their thinking requires explicit instruction in these tasks. Intervention studies of self regulated learning theories (Zimmerman 2000) support this assertion and provide examples of explicit strategy instruction that may be embedded within models of mathematical instruction. These interventions strengthens the case put forward by others that self-regulation is "a major objective of mathematics education... and... a crucial characteristic of effective mathematics learning" (De Corte et al., 2000, p.721)

"School mathematics should be viewed as a human activity that reflects the work of mathematicians-finding out why given techniques work, inventing new techniques, justifying assertions, and so forth" (Romberg and Kaput, 1999 p.5) Teachers can play significant role in creating an environment where interaction on shared meaning and understanding is the norm and supports participation. Teacher "think-alouds" can encourage critical examination of reasoning and participation in the resolution of disagreements. In this environment, students learn to master the thinking in the service of reasoning about important mathematical concepts

Typically, mathematics is viewed as a body of knowledge constructed of facts and procedures with success measured in mastery of the procedures. However, globalisation is causing a change in the measure of mathematical success. Globalisation has also been responsible for fostering international comparisons between the educational achievements in mathematics and specific abilities of age groups and gender. The OECD's Programme for International Student Assessment (PISA) 2003, has created a context in which national education systems in mathematics is compared to international standards.

Pisa 2003

PISA (Program for International Student Assessment) is a large-scale, three yearly international study that assesses knowledge and skills in 15 year old students. The study is coordinated by the Departments of Education of participating countries, under the supervision of the OECD. Students are assessed in three cognitive domains: reading, mathematics, and science. In 2003, PISA assessed mathematical literacy with a focus on problem-solving knowledge and skills. PISA defines mathematical literacy as "... an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments and to use and engage with mathematics in ways that meets the needs of that individual's life as a constructive, concerned and reflective citizen."

The study confronted students with real-life problems set in a variety of contexts and they needed to activate their mathematical knowledge and skills in order to solve these problems. Overall Irish students were ranked 17th out of 29 OECD countries that took part in the survey. Further analysis of this mid-ranking score reveals that approximately 11% of Irish students were successful in the more advanced levels of examination compared to the OECD average of 15% (Cosgrove, *et al.*, 2005). This relatively low-level of student achievement in mathematics at international level is most notable in contrast to reading literacy which places Irish students 5th out of 39 countries. "The comparatively low level of high achievers raises concerns about whether a post primary mathematics education is preparing a sufficient number of students to meet the demands of the knowledge society" (NCCA 2005, p.189)

The chief science advisor (McSweeney, 2005) has argued that mathematics plays a central role in the development of Ireland's knowledge society. However, concerns exist over the teaching of mathematics relative to Ireland's economic goal of active participation in the knowledge economy. Statistics published by the Chief Examiner's Office show that in the decade from 1994 to 2004, the number of students achieving a grade C or higher in Higher Leaving Certificate mathematics has dropped from 84% to 77%. Results in the 2005 examinations show that over 4000 candidates failed mathematics at Ordinary Level. Finally, the number of students taking Higher Level mathematics at Leaving Certificate is only17% which contrasts to over 60% taking

English and Higher Leaving Certificate level. The statistics correlate directly to our international rankings amongst OECD countries.

Inside Classrooms, Lyons *et, al.,* (2003) reveals that there is evidence of a high level of uniformity in how mathematics teaching is organised and presented: "front of class teacher demonstration of mathematical procedures followed by student practice with exercises taken from textbooks: 90% of lessons made use of textbook or a worksheet of some kind". Lyons *et al.,* conclude that "... all 20 lessons that we videotaped were taught in a traditional manner... most of the time was spent on exposition by the teacher, followed by a programme of drill and practice. Overall teacher-initiated interaction comprised 96% of all public interactions in the classes, and within this context a procedural rather than conceptual and/or problem-solving approach to subject matter prevailed. (p.367)

Memorisation and routine performance were given exceptionally high emphasis and logic, creativity and applications given very low emphasis. The chief examiners report in 2000 specifically notes an apparent lack of relational understanding, the ability to understand *why* rather than just *how* as a basis for applying knowledge in unfamiliar circumstances. In a report by Morgan *et al.,* (2001) difficulties with subjects which have a mathematical base have contributed to failure and dropouts from Institute of technology. Lecturers report a lack of ability by students to apply mathematical reasoning except in the most rehearsed and routine procedures.

While second level mathematics teaching in Ireland is under spotlight review at present, similar problems exist internationally. There have been two principle approaches to the teaching of mathematics over the last three decades, a formal approach known as 'modern' mathematics or Realistic Mathematics Education (RME). Realistic Maths Education is comprised of two core functions: Horizontal and Vertical Mathematisation. Horizontal Mathematisation "leads from the worlds of life to the world of symbols", and Vertical Mathematisation is the act of manipulating those symbols "mechanically, reflectively and comprehendingly".

The current mathematics curriculum (otherwise referred to as 'new mathematics') has a heavy emphasis on the logical aspects of mathematics. Specifically, it concentrates on the laws of arithmetic, geometry, and set theory. Since the 1960's the 'new' mathematics culture, with its elevation of abstraction as its core principle, has dominated (Irish) post primary mathematics teaching" (Oldham, 2001).Video evidence further suggests that the culture of mathematics teaching in Irish secondary schools is didactic and procedural in keeping with the new mathematics education as evidenced in the Third International Mathematics and Science Study (TIMSS 1999).

The basics are taught, then rehearsed by the student, until such time as there is a demonstrated competence in the operation. Once mastered, more complex operations and procedures are presented to extend the learner's ability and attempt to develop higher-order thinking skills. However, this linear approach of the basics first leading to the more advanced is flawed as it results in skills hierarchies controlling approaches to teaching and it can lead to miss construed relationships between different curriculum components (Means, Chellemer and Knapp,1991).

Procedural teaching of mathematics is a behaviourist approach which involves three basic strategies: teach the basic procedures, break the problem set into smaller chunks of manageable tasks, and then reward successful completion of the chunked tasks (the observed change in behaviour) with more complex procedures. This approach offers mathematics as a hierarchical assembly of manageable tasks. While this approach can simplify teaching design and lesson planning, it erroneously assumes that the learner can integrate these lower-level tasks into a structure that leads to higher order thinking. As the learner is involved in an artificial task assignment the learners are excluded from the process of real-world problem-solving. Difficulties will then arise when problems are contextually framed such as found in Word problems (Koedinger and Nathan, 2004)

Constructivist learning differs greatly from behaviourist learning from the premise that knowledge is constructed by the learner as opposed to the rote absorption of a body of knowledge. "Learning occurs not by recording information, but by interpreting it" (Resnick 1987). Constructivist learning is active and the knowledge created leads to meaningful understanding. "instruction must be based on what each learner knows, instruction should take into consideration how children's mathematical ideas develop naturally, and children must be mentally active as they learn mathematics" (Fennema *et al.* 1989 p.203).

Assessment on the behaviourist tradition involves an examination of how well students have mastered skills, progressing from simple to complex levels. Whereas cognitive assessment focuses on examining the learners' change in conceptual understanding often demonstrated in the application of new knowledge in real-world contexts. Due to the focus of 'new' mathematics on abstraction and the behaviour of focus on decontextualised skills, examinations test skills in tasks that are abstract and then have no relevance to the mathematics required for real-world application. *"the development of behaviourism has led to persisting views of learning hierarchies within mathematics, with harmful effects" according to Resnick (1987a, pp.48 to 49)* De Corte *et al.,* 1996, p. 493)

The National research Council in the US refers to three assessment fundamentals as a triangle incorporating cognition, observation and interpretation. Realistic maths education is an ideal tuition method suited to this form of assessment as it is most likely that interpretation will be demonstrated through the problem-solving technique used in a real-world situation where the learner has to mathematisise the problem prior to performing any procedure or operation are on the core data. (Van den Heuvel-Panhuizen, 1996)

The use of concept maps in the teaching of mathematics could assist students in the following ways;

- Concept mapping supports the natural thinking process which goes on randomly in a non-linear way. As concept maps have an open structure, one may just let one's thoughts flow; every produced concept idea may be integrated into the map by relating it to concepts previously drawn with relatively little mental effort.
- Concept maps let cognitive structures of students become visible. Maps drawn by students provide information about the students knowledge. The students knowledge of structure of a given topic becomes visible by means of concept maps for both the teacher and the student

- the student develops an awareness of his or her own knowledge organisation. This process can be enhanced by having the students in small groups, constructing maps by discussing the concepts required to be used and the connections to the drone
- connections between concepts made incorrectly can be investigated by the teacher with the student. The explanation given by the student could bring more insight into the underlying cognitive structure than the simple and reduced representation on the map
- students growth in the understanding of a topic can be checked when asked to create both the pre-and post-instruction unit concept map to demonstrate to the teacher if supplementary concepts are linked to the topic in a meaningful way.
- Each concept map has a unique appearance and a strong visual appeal. Information may be memorised and recalled faster with the learning process speeded up and structured information becoming longer living.

Hypothesis / Research Question

Internet technologies have changed the nature of knowledge with information on practically any topic now available through the World Wide Web. Information presented through Wikis, Blogs, Podcasts and instant messenging services create a demand to become adept at evaluating, analysing and synthesising the information they present. One could argue that it's more important to know where and how to get pertinent information as opposed to learning bodies of knowledge in isolation. Information and Communications Technologies (ICT) has been largely responsible for the globalisation of information availability and has spawned industries that are based on information technology. This in turn has created national economic dependencies on what has been previously called information societies but is now the Knowledge Economy. Much has been written in various economic forecasts and commentaries about growing dependencies on a Knowledge Economy and the requirement for mathematics and science subject graduates. Internationally, this has created a spotlight evaluation of education policies, curricula, teaching and learning.

The predominant focus in Ireland on the teaching and learning of mathematics is on results achieved in the Junior and Leaving Certificate examinations. Over the past decade there is a noted decline in the numbers of students who take Higher Level Mathamatics at Leaving Certificate level. The Chief Examiners office also notes a decline in the level of achievement in these examinations and expresses concerns that students seem more focussed on the 'how' rather than the 'why' of mathematics. Modifications to the curriculum and examinations appear to have had little other than a negative effect as the published results continue to decline. The literature reviewed draws attention to the "didactic manner" in which second level mathematics lessons are presented. Indications of a rote-learning approach to learning formulae to solve mathematics problems are also evident. It can be legitimately argued though, that the format of the Leaving Certificate examination and the time available to a secondary school maths teacher mitigates heavily against the teacher changing their teaching practices.

Mathematics and science related topics are most identifiable with logical thinking and problem solving. In the literature reviewed, some attention has been drawn to the research into some of the initiatives undertaken by other states that have changed their mathematics curricula. Realistic Maths Education (RME), as proposed by the mathematician and researcher Freudenthal, places mathematics into everyday contexts with significant motivational effects on students desire to discover the answer. This requires a new learning framework where the teacher changes their role as the source of the answer. Perhaps they don't have the answer but are willing to facilitate pupils' enquiries into strategies that might provide an answer. Approaches to the teaching and learning of mathematics that differ from the traditional application of routines and procedures invoke further investigation into the cognitive sciences such as working memory, cognitive load, dual coding theory and schema.

The purpose of this research paper is to examine the effect and potential improvement on learning outcomes that the use of Concept Maps with embedded hypermedia would have on the teaching of introductory algebra. Pupils in the last semester of their primary education were chosen for the study as they are outside the secondary system yet intellectually appropriate as they are will receive formal tuition in algebra at second level within the following six months. By presenting the subject in a different format to the typical method of classroom instruction, the study examines indications of improvement to pupils' problem solving skills, the integration of ICT as an 'open content' learning resource and looks for indications of pupils becoming self-regulated learners. Approaches to the teaching and learning of mathematics that differ from the usual application of routines and procedures invoke further investigation into the cognitive sciences such as working memory, cognitive load, dual coding theory and schema.

As there are documented limitations on the amount of information that working memory can process at the one time, literature concerning Cognitive Load Theory (CLT) was examined to explore how this aspect of cognition could impact learning. There are three types of cognitive Load: intrinsic, extraneous and germane. (Sweller 1998). Intrinsic cognitive Load occurs during the interaction between the nature of the material being learned and the expertise of the learner. Extraneous cognitive load is caused by factors that are central to the material being learned, such as presentation methods or activities that split attention between multiple sources of information. Germaine cognitive Load enhances learning and results in task resources being devoted to schema acquisition and automation. In other words, as learning occurs, increasingly sophisticated schemas are developed and learned procedures are transferred from controlled to automated processing. Automation, frees capacity in the working memory for other processing functions. This 'state' of automation could be referred to as the description of a *habit.* We explore through the use of Concept Mapping activities if the habit of scientific approaches to problem solving could be fostered.

These aforementioned aspects of cognitive science are of particular importance to the design of lesson plans. Based on the research on cognitive load theory, changes to the way new material to be learned is presented can have significant effect on learning outcomes if cognitive load could be reduced.

The research also explores learning outcomes under 'Goal Free' conditions. Scientific research in this area of cognitive theory indicates that there can be improvements to learning. By not providing an end-goal, the learner has greater capacity in working memory as they are relieved of having to maintain certain conditions which can interfere with their ability problem solve. Typically in mathematics instruction, students are provided with a worked example of a problem. While this can reduce cognitive load by providing a structure to work within, the research also sets out to explore if a deeper meaning can be achieved by 'self-explaining' which is a process that encourages students to take a break during the construction of their concept maps to explain the material to themselves thus reinforcing their own understanding of the subject material.

2. Method

This section provides an overview of the design and selection of the multimedia materials used during the research. It also examines the selection of students partaking in the experiment and how the study was conducted. Also discussed are the instruments used and applied in the data collection as well as the operationalisation of the research component of the study.

2.1. The Sample

As referred to earlier in this paper, existing research into problem solving and critical thinking relative to mathematics teaching, is focused predominantly on second level students. However, several factors were considered prior to selecting a suitable study sample. The study was designed to introduce concept mapping, familiarise students with the use of ICT through concept mapping software and to use of multimedia units of instruction in basic algebra. Given the relative time constraints, access to school computers, availability of the maths teacher to undertake certain activities and appropriateness of the algebra units, it was decided not to use secondary students. Instead, sixth class primary students were deemed to be more appropriate to the nature of the study for several reasons:

- They had little or no prior knowledge of algebra.
- An introduction to algebra is a strand of the primary curriculum.
- There is a greater occurrence of computers in the classroom at primary level
- The primary teacher was more likely to have flexibility with the daily timetable
- Creating small workgroups to work collaboratively is a more common feature in primary teaching than in secondary.
- Familiarity with other students would contribute positively towards the goals of working together collaboratively.

Consideration was also given to the idea that an objective of the study was to make students aware of the potential positive benefits that the creative thinking activities could have when applied to mathematics problems that they were likely to encounter later in their education. It was further intended that the students become aware that mathematical reasoning is not only a curricular tool but a life skill.

Using a list taken from the Department of Education and Science website, a telephone survey of randomly chosen schools in the Dublin area was undertaken. The objective of this survey was to establish the presence of two or more computers in the sixth classes. It was also necessary to establish if there was broadband Internet access available in the classroom and that's the computers were fully functional. In almost all cases a call back to the schools required as the school secretary was not aware if these conditions existed and had to check.

Five primary schools were identified as potentially suitable sites to conduct the experiment. Initially, the letter explaining the purpose of the study was sent to each Principal to request their cooperation in a teaching experiment using concept maps and multimedia to deliver algebra lessons to sixth class pupils. A follow-up phone call was made to inquire of the Principal had the opportunity to discuss the proposal with the sixth class teachers. This also required a follow-up phone call seeking the response of the sixth class teachers.

Three of the schools, while expressing an interest in the experiment, were unable to commit to participating in the research due to a combination of other school commitments, preparation of pupils for entrance examinations to second level, school tours and preparations for Confirmation ceremonies. Of the two remaining schools who expressed initial interest, one had previously committed to partake in a study by a psychology student and subsequently retracted their offer to participate in the concept mapping study. The remaining school not only had the required technology in place but the sixth class teacher had a personal interest in concept mapping and considered that the practice would benefit the pupils when they had moved into second level education.

In conjunction with the class teacher, an appraisal of each student's ability in mathematics was undertaken in one afternoon after school hours. The most recent results from the Drumcondra Tests in mathematics for the class were examined to establish an overview of the mathematical abilities of the class. The mean result in mathematics for the class was 67%. From a total class of 29 pupils, 12 pupils of mixed ability were chosen based on half the group having scored higher than 67% in the Drumcondra Tests and the other and the other half having scored below that. No distinction or importance was placed on the sex of the student during the selection process. The selected group consisted of five girls and seven boys. Once the pupils agreed to participate in the experiment, they were given a consent form to be signed by their parents.

2.1.1 Teacher Co-operation

The class teacher, while proficient in general computer use, did not normally incorporate ICT into classroom instruction. Two PCs were available in the classroom, each with a selection of educational software installed and a DSL Internet connection. To facilitate this research, two copies of concept mapping software were installed onto the two PCs. Resulting from the existing abilities of the teacher and the relative ease of use of the concept mapping software, less than one hour of guided instruction on the software was required from the author. The instruction consisted of skills based training highlighting the various feature sets of the software that are used for graphic enhancement of concepts, text formatting and hyperlinking.

A copy of the concept mapping software was given to the teacher for personal use on his home computer which also afforded him the facility to become more conversant with the features of the software outside the guided instruction. A brief instructional manual highlighting the principal features of the software was also presented to the teacher for later reference if required.

2.1.2 Pupil Co-operation-Induction

Pupils were introduced the concept mapping using content using the suggestions of Novak in the 1984 publication Learning to Learn. The pupils were introduced to concept mapping on a phased basis over two weeks as follows;

Introduction to Concepts

Following the suggested method of introducing students aged nine to 13 by Novak the 12 students were presented with a word and asked to picture the word in their minds eye. The first example used was the word Apple. Pupils were asked to close their eyes and the word was repeated three times. Then pupils were randomly chosen and asked to describe what they saw. Initially, the answer in each case was simply "I saw a picture of an apple". Unanimously, none reported seeing just the individual letters A P P L E. The next line of questioning was more probing. Pupils were asked to guess if everybody saw the same image of an apple. This cause them to reflect momentarily followed by some suggestions that some a saw red apple while others saw a green apple. Pupils were then asked to identify if they saw the image of the apple in isolation, on a tree, in a supermarket display or any other location. Following a brief discussion it was established that no two images of the apple were the same but the word Apple conveyed the meaning of an everyday fruit. A list of 10 words were explored in this manner, the last example was dog. The pupils noted that although there are many types of dog the image created internally was that of a four-legged creature that barks. Pupils were then instructed that words convey meaning to them when they represent pictures or meanings in their mind. Finally a distinction between proper nouns, for example place names, and concept words was established agreeing that proper nouns generate specific mental images and are therefore not concept words.

Introduction to Events

Following the procedure outlined above, pupils were then introduced to a new list of words like rain, wind, fall etc., which were termed 'event' words. Rain, the action of water falling from a cloud, generated many different images all of which portraying the same meaning.

Linking Words

The third list of words was introduced. Of, and, in, and seven other words were presented to the pupils. After the first or second word was given from this list, students recognised that these words did not produce a mental picture. These words were termed linking words which are used to link concepts together. Using the list of concept, event and linking words, pupils were asked to create concept-link word-concept units. They created numerous units like "plant-is-green" and "dogs-can-swim".

Concept Mapping

Following the introduction and explanation of concepts, pupils were encouraged by the class teacher throughout lessons to identify concept words. This procedure assisted the pupils in becoming familiar in identifying legitimate concept words. The next element of instructing the pupils was to introduce them to the idea of taking the list of concepts and creating a hierarchical structure with them. Pupils were asked for concepts related to a plant. After collecting approximately 10 concepts relating to plant, each concept was transcribed onto a PostIt note and placed randomly on a whiteboard. The process of creating a hierarchical structure began with the group consensus that the word plant was the most general term and should be located at the top of the hierarchy. Subordinate concepts like leaf, stem, route, green, water, were then arranged in order leading from the most general and inclusive concept down to the more specific. When the hierarchical order had been agreed with the group connecting lines were drawn between each concept and annotated with linking words to illustrate the connections between the concepts.

2.3 The Procedure

The research was designed to coincide with the schools curricular timetable where algebra tuition is introduced post Easter holidays in the final semester of sixth class. The pupils had received no prior instruction in exploring the concept of a variable in the context of simple patterns, simple formulae and substitute values from variables as prescribed in the algebra strand of the sixth class mathematics curriculum.

With the co-operation of the class teacher, the group of 12 students were excluded from normal teacher led classroom instruction on variables and simple equations. During this time, they were instructed on the use of the concept mapping software, Inspiration. The instruction given was exclusively skills focussed as the students rehearsed creating various geometric shapes to house concept labels, creating link lines between concepts, formatting text, creating hyperlinks, saving and opening files. Within 30 minutes of guided instruction using a data projector and some borrowed laptops, the pupils undertook "hands on" instruction and had a comprehensive understanding of many of the functions of the software.

Inspiration software is typical of many concept mapping packages but was chosen for the experiment for numerous reasons;

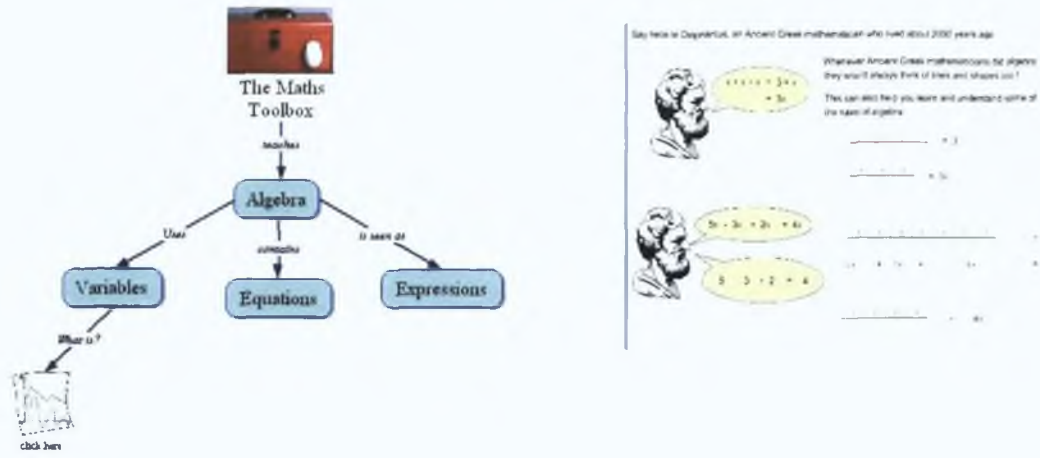
- Availability of fully working 30 day demonstration version.
- Online tutorial modules
- Availability of templates and help files on the Web
- User-friendliness
- Familiarity with the software by the author
- Facility to hyperlink to pre-prepared mathematics instructional video files
- Brand leader in the education market

2.3.1 Mathematics Toolkit

There are many educational software packages available for the teaching of mathematics. These range from web based Flash™ applets -usually found on study guide type web sites, online tutor lead instructional courses, and off-the-shelf CD-Rom packages. In preparation for this study a comprehensive review of commonly available packages was undertaken. Possibly due to the size of the marketplace, it was not possible to locate a software that was either locally made or specifically written to match the Irish mathematics curriculum. The software review revealed that most of the packages were unsuitable for use in the study and the appropriate material would need to be developed. Due to time limitations it was not possible to develop a sufficiently wide range of tutorial videos.

Using a 15 day trial subscription to an online tuition service "Hey, math", algebra tuition content that was consistent with the material being presented in class by the teacher was identified. Hyperlinks to these individual tuition modules were then created and stored within the concept mapping software.

Screen Shot from Mathematics toolkit



Once familiar with the Concept Mapping software and having had time to rehearse making paper-based concept maps on various topics, the pupils were introduced to the mathematics toolbox as a set of tutorial files to be explored. Over a period of two weeks, the pupils were given time during group work activities to look at the instructional videos and to write notes on any aspect of the instruction that was unclear. The teacher was requested to note the students' comments as they interacted with the instructional software. Due to classroom management issues, this level of observation and note-taking by the teacher was impractical and was not recorded.

2.3.2 Problem Solving

In the third week of the experiment the students of the focus group were presented with a worksheet of word problems. The word problems were each set in a realistic context and the pupils were asked, as a group, if any of the multimedia material that they had been examining over the previous two weeks could be used to solve the worksheet questions. They were assigned the task of constructing a concept map with links to appropriate video files to create an overview of the mathematics required to solve the problems. The focus of this activity was not to get an answer but rather to establish if the pupils saw a connection between the realistic problem in context and the abstract context of the video instruction files. To successfully complete this activity, the pupils were asked to put the problem into their own words to see what strategies could be applied to solve the problem.

2.4 Research Design

This study was implemented with a small group of primary school students in order to explore the potential of using concept maps to develop self regulated learners under mathematics instruction. The study further sought to explore the potential for improvement in students' problem-solving skills while working in collaborative groups using mathematical problems set in a real-world context. The process of development research was employed during the study. Working in conjunction with the class teacher, a sequence of instructional activities were implemented with a total of 12 learners over a three-week period. Research was recorded in three phases; Observation, Application and Data Collection.

Observation: In this first phase of the research, notes were taken by the author outlining students' comments and interaction with the learning material. This phase was limited to the first week of the inquiry. During this time, particular attention was given to how the students interacted with each other. As the students would be working in collaborative groups throughout the study, it was important to note each student's willingness to contribute and participate in the exploration of the new learning material. Familiarity with computer use, understanding of instruction and multimedia terminology (hyperlinking, url, etc) were also observed. Information gathered from these observations would be used as a measure to ensure equality between each of the collaborative groups. Each of the students took an online Index of Learning Styles Questionnaire developed by Soloman and Felder of North Carolina State University. From the results, students were divided into work groups with mixed learning styles; Active and Reflective Learners, Sensing and Intuitive Learners, Visual and Verbal Learners and Sequential and Global Learners.

Application: in the second stage of this action research, using the information gathered in the observation phase, the working groups were formed. The four groups of three students were each given a worksheet of mathematical problem set in a real-life contexts to see if they could put the question into their own words and then observe their interaction as they negotiated the problem and devised a strategy to create a solution. This process in RME is referred to in the literature as the ability to mathematisise. It was explained to the students, that the answer to the problem (if there was one) was far less important than the procedure they used in their attempts to solve the problem. Prior to the commencement of any concept mapping or a multimedia work each student in each group was requested to write in their own language series of steps that would be required to solve the problem. The qualitative analysis of the procedural steps suggested by each student was also examined.

Data collection

Two data sources were used for the study. An evaluation of the accuracy and appropriateness of the concept maps produced by the students was generated in accordance with the scoring system suggested by Novak & Gowin (1984) and a qualitative survey was also employed to establish the following;

- how the students felt about the use of concept maps as a learning tool
- if the uncertainty of not knowing if a solution was possible or not effected their reasoning
- Any expression of preference for the role of the teacher to be a facilitator of inquiry or the source of the answer.
- Did the students feel any positive benefits from this form of instruction.
- Could they use concept mapping in other subjects.

3. Results

The research design section of this paper explains that an objective of this study was to create a learning prototype featuring a combination of realistic mathematics education, self regulated learning strategies and the use of ICT. It had been intended to use observational notes taken by the teacher during the times that the sample group were constructing pen and paper concept maps. As mentioned previously, such notes were not taken.

The survey undertaken, comprised three distinct elements; Section 1 of the questionnaire focused on the opinion of each student regarding the use of concept mapping as a learning tool. Section 2 examined if the students were beginning to display and the aspects of self-regulation in their approach to problem-solving. Finally, Section 3 of the questionnaire asked the students to put seven steps of a problem-solving strategy into the correct sequence. The survey questions were asked at various times throughout the study and recorded by the author to produce an ongoing assessment of the student's attitude and abilities during the experiment.

Section 1.

Q1. Which is easier for you to use when solving a maths question?

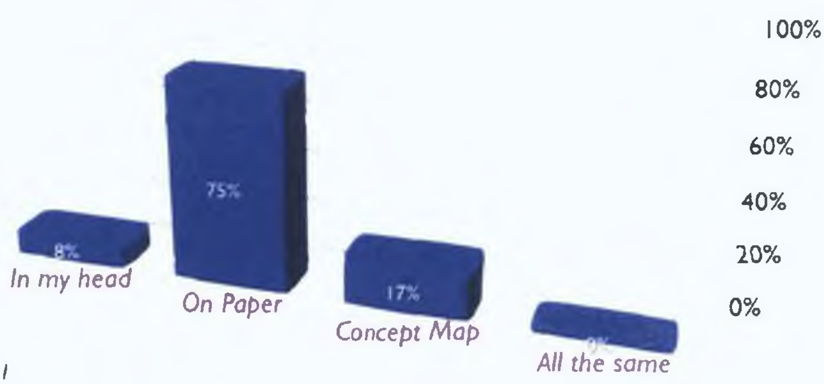


Fig 3.1

This question was asked immediately after the initial training was given on the use of the concept mapping software. In the days prior to this ICT training, the students had been practising using pen and paper to construct a variety of different concept maps in situations and subjects as dictated by the class teacher. While the students expressed a great interest in continuing their concept mapping activities with the use of ICT, their familiarity with creating concept maps on paper dominated the response to this question indicating a preference for a hand drawn concept maps. Furthermore, the class teacher subsequently advised that only one of the practice concept maps drawn by the students concerned a simple arithmetic problem. Neither had the students been given time to explore the mathematics toolkit indicating that they may not have seen a clear correlation between the use of concept maps and problem-solving in mathematics.

Q2. When working out a problem, which method do you prefer?

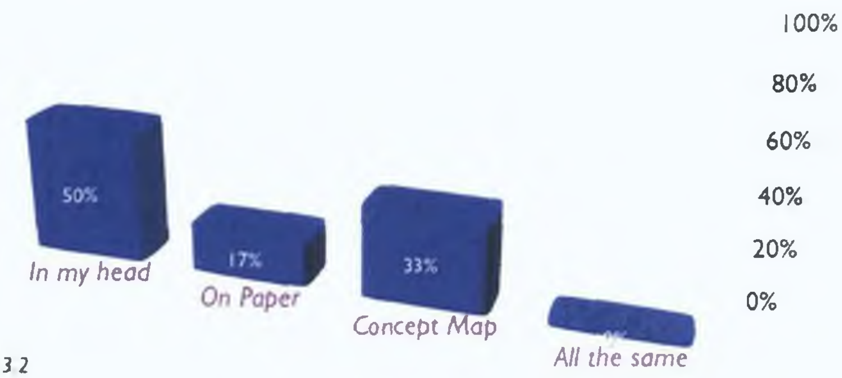


Fig 3 2

The responses to this question are indicative of a change of opinion by the students to their preferred method of working out a problem. In the previous question, 75% of the students indicated a preference for a problem-solving on paper - specifically when attempting to solve a maths problem. Question two generalises the question of problem-solving by excluding any reference to maths. There is a suggestion here that students are becoming cognisant of the need to think about a problem first before employing paper-based or concept mapping strategies to find a solution.

Q3. Which helps you to remember the rules of algebra better?

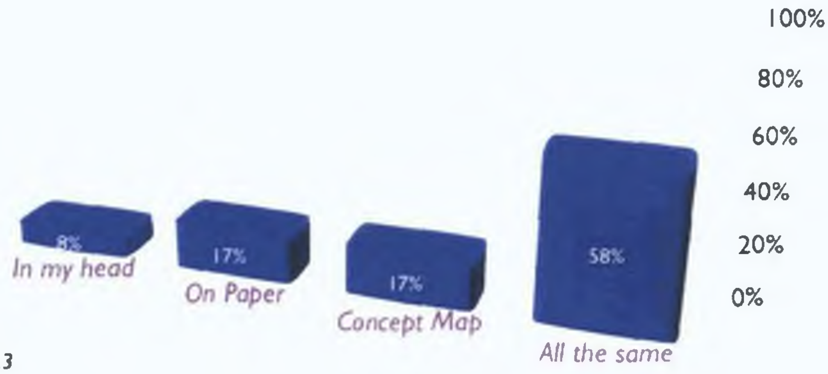


Fig 3.3

This question was asked of students shortly after they had been given the opportunity to explore the multimedia instructional units in the mathematics toolkit. Considering that the students had previously expressed great interest in using concept maps and subsequently an equal interest in the use of ICT to produce concept maps, that 58% of the students reported no difference between the strategies offered seemed unusual. As the survey questions were delivered on an ongoing basis, it was the opportunity to further analyse this response. The students who have expressed no specific preference of one strategy over another, suggested a misinterpretation of the question. They had assumed that the rules of algebra was a set body of knowledge and that they had not seen these rules yet.

Q4. Do you prefer using the computer or pen and paper to make concept maps?

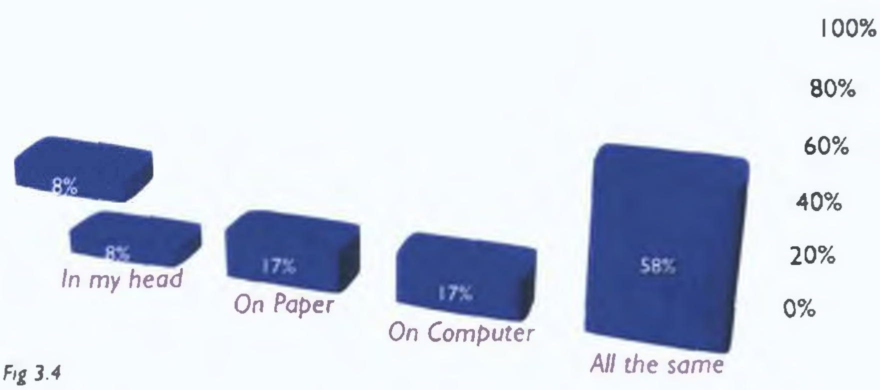


Fig 3.4

The students were asked this question a few days after they had been familiarised with the concept mapping software and had been afforded time during class to create concept maps on the PC. 67% of the students preferred making concept maps on computer and indicated that the primary feature of the use of ICT in this way was the availability of graphics from the software's graphics library which enables them to create colourful and stimulating concept maps in a very short period of time. Time was an important issue for the students as they had only shared use of the classroom PCs and a limited amount of their school day was focused on mathematics activities. The students who expressed a preference for creating concept maps on paper typically produced concept maps with fewer levels of hierarchy but their maps tended to contain more ornate graphics. The students further explained that they wanted to be careful not to have to redraw their maps and so took their time over the positioning of items within the hierarchy.

Q5. Which do you think is better for taking notes?

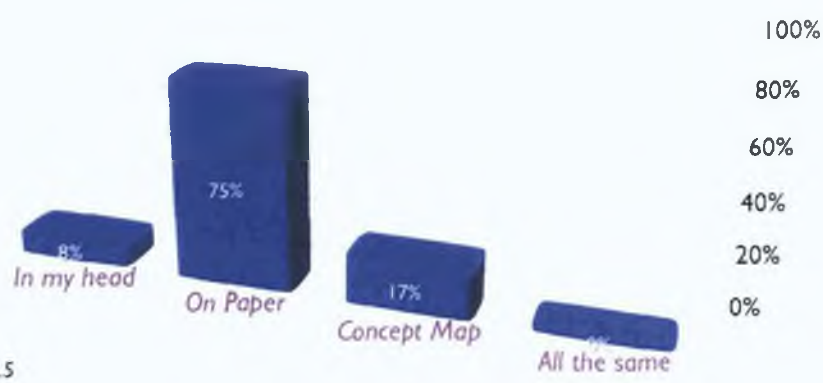


Fig 3.5

This question set out to establish the fluency with which students felt they could develop a concept map. The question enquired about the students ability to take notes on any topic using a concept map as a structure for note taking. The majority preferred the traditional means of linear text which they would later translate into concept map format. In discussion with the students as a group on this issue, the consensus was that it was difficult to construct a concept map without first of all having an overview of the subject material. This point has implications for lesson plan design and delivery and would indicate that in this instance, these students do not typically receive an overview of the instructional unit prior to teaching. This suggests that the students are a familiar with the linear approach to learning where the basics are learned first followed by a progression to the more advanced. This has been referred to in the literature review as a potentially flawed method of instruction at it can lead to misconstrued relationships between different curriculum components (Means, Chellemer, and Knapp, 1991).

Section 2.

Q6. Does it matter if the teacher knows the answer or not?

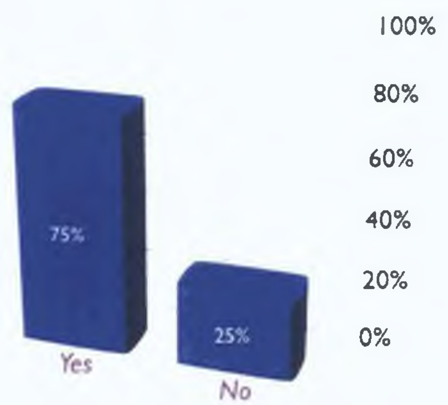


Fig 3.6

The majority of students in this case preferred that the teacher did know the answer. This is most likely a reflection on the classroom environment in a primary setting where the teacher is perceived as the primary source of instruction, information and discipline. At the time this question was asked, the students were not proficient in producing concept maps. Neither did they have much experience in exploring relational links between the concepts in their maps.

Q7. Is it better to solve problems in groups?

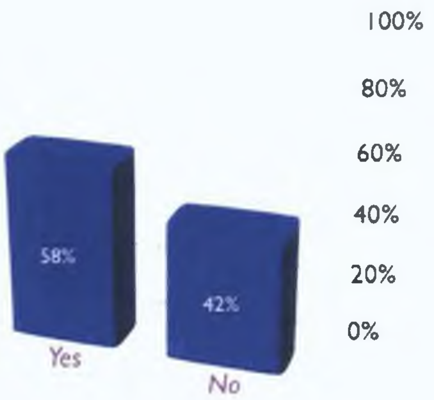


Fig 3.7

There was a mixed reaction to this question. Slightly more than half of the students expressed a preference for problem-solving in groups. The groups referred to were the ones that they were split into four the purpose of the study. Assignment to a group was dependent on their indicated learning style resulting from the Solomon Felder index of learning styles. This may have had a bearing on the response to this question as the groups represented an equal mix between active and reflective learners.

Q8. Do you think that concept mapping causes you to think differently about solving maths problems?

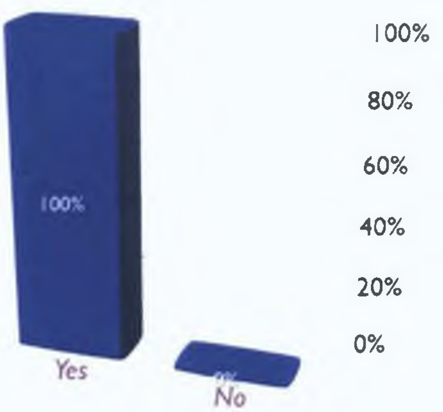


Fig 3.8

All of the students responded positively to this question. At the time of asking, the students were demonstrating a proficiency in producing concept maps. They reported that "you have to think the problem through a bit first..." before you can begin making a map. On further investigation, when they were thinking the problem through they were in fact mathematisising by seeking the arithmetic elements of the problem before constructing their map.

Q9. Could you use concept maps in other subjects?

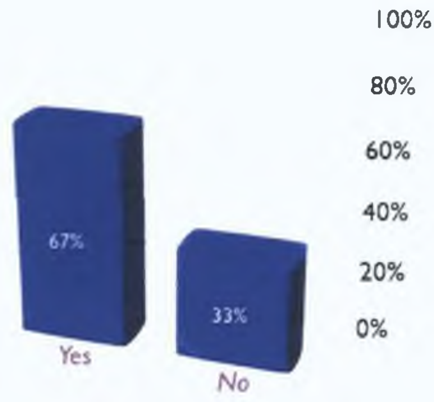


Fig 3.9

Question nine was posed to see if the students felt that the processes involved in creating a concept map could be transferred to other subjects. All of the tuition regarding concept maps had been focused exclusively on the use of solving mathematical problems. It would be possible to surmise that the 33% who did not see that concept maps could be used in other subjects had not fully grasped the process of deductive reasoning dictated by concept mapping. The group was not only mixed by their learning styles but also by their abilities. Some of the lesser able students responses may have influenced the overall response to this question.

Q10. Do graphics added to your concept map make any difference to it's meaning?

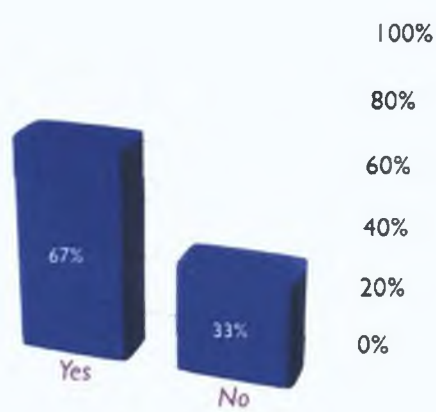


Fig 3.10

Considerable time had been spent with the students assisting them to post edit their maps to make them more meaningful to them. This was achieved through applying colour to different levels of concept hierarchy and using emphasised text (bolded and italicised) to indicate levels of importance. These enhancements are considered to be potent memory stimulants (Buzan 1986) yet a considerable proportion of the students felt that the graphics available to them did not enhance meaning. When questioned further on this topic, the majority of those who answered negatively felt that the images available within the software were inappropriate to their maps and therefore didn't use them.

Q11. Does multimedia in the concept map make a difference?

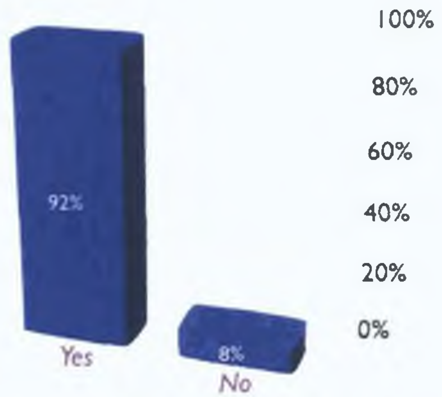


Fig 3.11

Almost all of the students considered the use of multimedia embedded into a concept map contributed positively to the effect of the map. The students had been introduced to concept mapping with the mathematics toolkit available to them and had received instruction on how to hyperlink from their maps to multimedia files. They expressed a preference for concept maps that had links to multimedia components as they felt that these links reduced the need to have an expansive map as a lot of explanation was available to the learner in video format. Referring to the learning styles once more, overall preference for multimedia in the concept map could be due to the number of learning styles that a multimedia concept map accommodates.

Q12. Does your concept map help you to understand better?

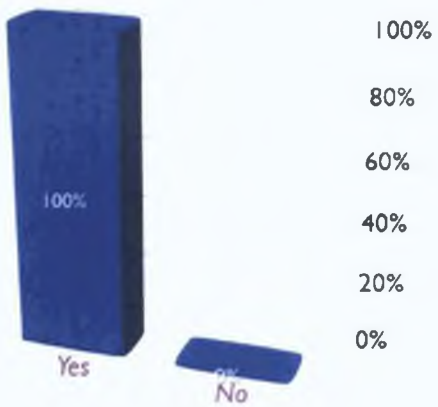


Fig 3.12

Each student responded positively to this question citing examples of how the concept map acted as a catalyst which helped them to think the problem through.

Section 3

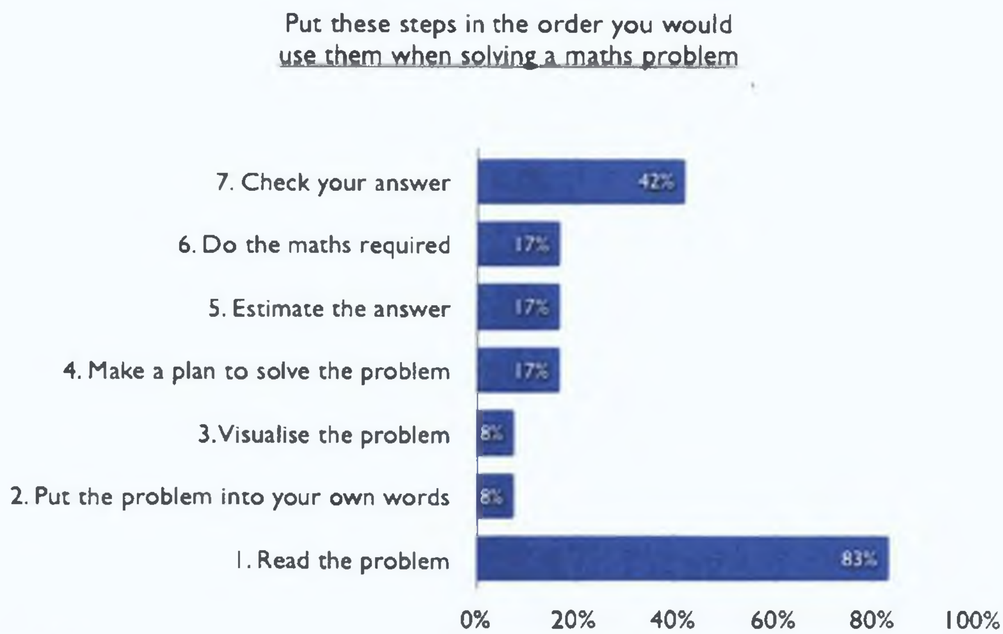


Fig 3.13

In this section of the survey, students were presented with an unordered list of suggested steps to be taken when solving the problem. Horizontal mathematising as previously referenced, engages the student in evaluating the problem to extract the core information to which the appropriate arithmetic can be applied. The graphed responses illustrating the percentage of students who correctly predicted each step in its correct sequence demonstrates that steps two and three, putting the problem into their own words and visualising the problem, received the lowest priority. Step seven, checking the answer, received the second highest priority in the sequence. This reflects a perceived high importance on delivering the correct answer which contrasts with the students placing a lower importance on demonstrating how the answer was achieved.

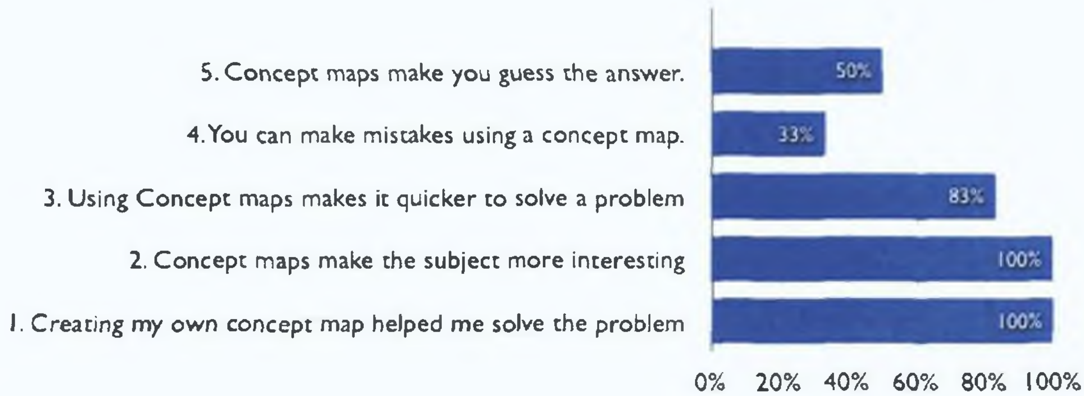


Fig 3.14

The final part of this qualitative assessment sought to establish student's satisfaction in the use of concept maps from learning. In conversation with the students shortly after the results were collated, they indicated a strong preference for the future use of concept maps to help them solve problems. They also suggested that the use of a concept map made of them think in a different way to the way they would normally engage in a problem-solving activity. None of the students felt that using a concept map made the task easier but felt that it gave the more scope to examine the problem and explore a more solution possibilities. This additional facility was also credited with making the subject more interesting.

Question 3 was used to investigate if the students felt that the use of concept maps assisted them in reaching a solution to the problem quicker than they would normally. Although a high proportion claim that it is a mechanism that helps them to problem solve faster, they commented that quicker solutions most likely came about as the structure of the concept map help them to coordinate and organise their thinking.

Question 4 evoked much post survey discussion. Some of the students suggested that the act of using a concept map was designed to help you make mistakes but in so doing recognise that either the position of the concept within the map was inappropriate or that the relationship link was incorrect. They viewed this as a positive attribute of using the concept map as mistakes were not really mistakes but the process of eliminating inappropriate hypotheses. There were clear indications of preferred learning styles as the global learners expressed their desire to explore, to test and evaluate their concept maps while the sequential learners preferred not to make "mistakes" by committing a concept or relationship link to the map without being fairly certain that was correct.

Question 5 sought to explore its students felt that the creation of a visualisation of the problem through a concept map assisted them in estimating a solution. Just over half of the students thought that the concept mapping process naturally brought them to estimate the answer. By defining the concept's required for a possible solution, they were "guessing" what the answer might be.

4. Discussion

The OECD's PISA 2003 study which focused on the problem-solving skills of an average 15-year-old in mathematics and the resultant mid-ranking score by Irish students, has drawn increased attention to the teaching of mathematics at secondary level in Ireland. The literature reviewed illustrates that problem-solving skills are considered to be of critical importance for concerned, informed citizenry of the 21st century. Mathematics curriculum designers in international education systems are striving to incorporate a greater focus on problem-solving skills. In the Irish education system at secondary level there are many factors which govern the design and teaching of the mathematics curriculum. Not least the points system required for entry to third level education. The object of secondary mathematics teachers is to assist their students achieve the highest scores in their Junior and Leaving Certificate examinations which has been seen to lead to the development of examination techniques through the rehearsal of procedures as opposed to creating an environment of mathematical investigation. As success in the secondary education system is tied to the points system, there is little scope for dramatic experimental change.

The first real challenge to their problem-solving abilities comes about when students are introduced to word problems. Early examples of word problems are typical of the type "John had three apples. Then, he bought four more. How many apples did John have altogether?" To extract the arithmetic components of this problem requires a student to perform their first horizontal mathematical task. At this point it will have engaged in a visualisation activity as they attempt to picture the total number of apples and will have applied the vertical mathematical procedure of applying the operators to reach a solution. When the primary focus on mathematics tuition is predominantly on operations and procedures with little attention given to visualisation and mathematisising skills, the development of problem-solving strategies embodied in the different learning styles are impeded.

Visualisation, as discussed in the literature review concerning dual coding theory, is a very powerful means of representing the problem and externalising the student's schema of connected ideas. During the instruction on concept mapping with our sample group of students it was noted overall, that explicit instruction on how to create visualisations of the problem was required. This finding concurs with the research of Butler (2002) and Zimmerman (2000) in their *intervention* studies of self regulated learning environments. Once problems were visualised to the creation of a concept map the next challenge that the students had difficulty with was consideration of the relationships between the problem components. This was found to be the centre point of the problem-solving difficulties as without an understanding of the interrelationships of the problem components, the students were unable to make a plan to establish a solution.

Students are confronted with problem-solving tasks from early in primary school. These tasks are often completed by the application of procedural routines in mathematics tuition. The students observed in this study displayed strong tendencies and almost a sense of urgency to apply arithmetic to reach a solution to the problem posed. The context of the problem was of less importance than the achievement of a solution. The introduction of algebraic thinking was confusing for some as they were unfamiliar with teasing out a problem or discussing possible strategies. As arithmetic is limited to numbers and numerical computations, manipulation of the abstract concepts alerted the students to the notion that justification of the use of a particular procedure was more important. They recognised the greater challenge to the cognitive abilities as that was more to "think about".

Numerous articles referred to the difficulties that students have when making the transition from arithmetic to algebra. They have to deal exclusively in the abstract through algebra. The introduction of basic algebra in class work and the challenge that algebraic thinking imposes on a students cognitive abilities, offers an early opportunity to develop strategies for problem-solving

An essential part of mathematical problem-solving involves a number of cognitive activities and strategic processes. Mathematisising involves two processes: problem representation and problem execution. By appropriately representing the problem students will have developed a basis for understanding the problem and subsequently making a plan to solve it. Students who have difficulty representing the problem, or in other words putting it into their own words, will have difficulty solving the problem. This difficulty is most apparent when students approach early algebra as it deals with the abstract and their visualisation skills have not been sufficiently developed to deal with this leap in arithmetic processing.

Negotiation of strategies with peers in advance of any concept mapping activity, created lively exchanges between the students. This contrasted noticeably with the others in the classroom who were receiving direct instruction. Careful control of the discussions was required to facilitate the student's focus on the legitimacy of the strategies being suggested. It was determined at this stage that specific steps would be required so that the students could apply a template of inquiry.

The students were introduced to cognitive strategy instruction procedures which have been previously demonstrated to be powerful interventions for students who have difficulty with horizontal mathematical reasoning (Swanson, 1999). Prior to formally introducing the students to the strategies, they were given a list of seven steps and asked to sequence the steps in the correct order. In the results section we saw that none of the students were able to put the sequence in its correct order. This pre-test of their abilities indicated a low priority amongst the students to put the problem into their own words or to create a visualisation of the problem. The tendency was to read the problem and then assume that the required arithmetic would be obvious. A high percentage of the students correctly predicted that the last operation of the sequence, to check the answer, was the final thing to do.

Classroom management became a growing issue during the time of the experiment. The class teacher expressed discomfort with the open conversational approach required to problem solve for the experiment. Difficulties between the management issues regarding teacher led, direct instruction and learner-centred facilitation in a constructivist environment arose. In the constructivist environment, learners construct their own understanding rather than having it delivered to them. The learning process is enhanced by social interaction were learners use and express their own experiences to construct understandings that make sense to them. The social interaction element in a constructivist based lesson encourages students to verbalise their thinking and subsequently refine their understanding by comparing it with the understanding of others. Learning in this type of activity encourages explanations and answers to come from the learners, not from the teacher. The role of the teacher is to help students construct knowledge by guiding the social interaction and providing content.

In a direct instruction teaching environment, the teacher takes a central role in explaining, modelling, and providing opportunities for practice with feedback. This skills based teaching model begins with the teacher introducing the students to the skill. The students then learn about the skill, how it's applied and where it can be used. Next the teacher demonstrates the skill, explains how it works followed by directed practice activities. The students then rehearse the activity under supervision of the teacher and receive feedback that is immediate, specific and provides corrective information for the learner. A strong feature of direct instruction is that it facilitates classroom management effectively by restricting interruptive behaviour by the students. The class teachers inferred a strong preference for this type of teaching.

The concept maps produced by the students were most frequently created on paper and the majority of these were created during the author's visits to the school. The students did explore the Mathematics Toolkit but used it mostly as a reference citing specific instructions viewed during the negotiations to produce concept maps to solve the worksheet problems. The intended objective of getting the students to undertake "self-explaining" activities by recreating interactive concept maps using ICT was limited due to infrequent access to the class PC's.

Concept maps, as defined in the literature as an externalisation of thoughts in a knowledge domain, were introduced to the students as a structure to assist their visualisation skills. Novak describes the human ability to think in concepts as a natural skill that we have from birth. The fast pace in which the students adopted the use of concept maps indicated that their use could be used could be used as a powerful teaching tool. The students selected for this study were an equal mix of above and below the class average in maths and a combination of learning styles. Although concept mapping seemed a little "strange" to them at first, they were able to employ the techniques of concept mapping into ICT usage in the classroom with little effort.

During the evaluation of mathematics software undertaken during the research project it was established that the vast majority of this type of software was a type referred to as skill and drill. This generates a difficulty for teachers incorporating ICT into classrooms as they try to find an exact match between a skill and drill software set at an appropriate level that matches their class work. Resulting from only 30 minutes instruction in the use of concept mapping software, students successfully combined the new process of concept mapping for meaningful learning while simultaneously developing their ICT skills. This would suggest that a different approach, other than "plug and play", "skill and drill" software usage could lead to a more seamless integration of the use of ICT even in the absence of specifically made Irish curriculum based software.

Despite the best efforts of the participating school and the class teacher, there was limited access to the students due to school commitments and time available to the researcher. The study also revealed potential issues regarding teacher workload and classroom management issues. Due to the short period of time made available for the research the results can only represent a snapshot view of a learning intervention. While the results overall appear to be positive, the author is reluctant to speculate on the long-term achievements that might be possible due to the number of variables involved. The class teacher, while very generous with their limited time, remarked that the presence of a second adult in the classroom was disruptive. Furthermore ad hoc open access to the classroom PCs by the students in the study generated class management issues that were tolerable for the duration of the study but were unlikely to be accommodated into the future. The limitations of time, regular access to pupils and the introduction of non-standard curriculum lessons also have a bearing on the research findings.

5. Future Perspectives

The international focus on the teaching of mathematics and efforts to increase the problem-solving aspects of national curricula gives cause to examine every factor of mathematics teaching. The PISA report from 2003 specifically targeted 15 year olds under problem-solving abilities. The mid-ranking score achieved by Irish 15 year olds prompted negative commentary from the media and industry about about mathematics teaching at secondary level. However, as the literature research has shown, students who do not take Higher Level Junior Certificate mathematics are unlikely to take higher level mathematics at leaving certificate level leading to a fall in demand for mathematics and science based subjects at third level.

Students have their problem-solving faculties challenged long before they enter secondary education, therefore it would appear to be a narrow based argument that focuses exclusively on the development of problem-solving skills in students aged from 13 to 15. This study has established indications that schoolchildren in the latter years of their primary education have spent several years learning procedures and routines in mathematics that they find difficult to apply when trying to manipulate abstract concepts. This is not unusual and is well documented in the literature concerning the teaching of algebra to classrooms worldwide.

The intervention of the use of concept maps was demonstrated to have a positive effect on learning outcomes but did increase the workload of the teacher involved. These have been previously referred to as practical issues regarding disruption to the class caused by the two groups being taught separately in the one classroom. But are concern at another level is that the concept mapping to be introduced effectively, cognitively guided instruction would be required with the teacher acting as a facilitator of constructive mathematical inquiry. Further research into pre-service teacher education and in-service professional development would be required to investigate if car that have guided instruction as a teaching format was feasible in our context given curriculum demands and typical class sizes.

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Appendix

Concept Mapping Survey

Q1. Which is easier for you to use when solving a maths problem?

- ☐ In my head
- ☐ On paper
- ☐ Concept Map
- ☐ All the same

Q2. When working out a problem, which method do you prefer?

- ☐ In my head
- ☐ On paper
- ☐ Concept Map
- ☐ All the same

Q3. What helps you to remember the rules of Algebra better?

- ☐ In my head
- ☐ On paper
- ☐ Concept Map
- ☐ All the same

Q4 Do you prefer using the computer to make concept maps or pen and paper?

- ☐ In my head
- ☐ On paper
- ☐ On computer
- ☐ All the same

Q5. Which do you think is better for taking notes?

- ☐ In my head
- ☐ On paper
- ☐ Concept Map
- ☐ All the same

Section 2

Q6. Does it matter if the teacher knows the answer to the problem?

☐ Yes
☐ No

If no, please explain why ______________________________

____

Q7. Is it better to solve problems in a group?

☐ Yes
☐ No

If no, please explain why ______________________________

____

Q8. Do you think that concept mapping causes you to think differently about solving a maths problem?

☐ Yes
☐ No

If no, please explain why ______________________________

____

Q9. Could you use concept maps in other subjects?

☐ Yes
☐ No

If no, please explain why ______________________________

____

Q10. Do graphics added to your map make any difference to it's meaning?

☐ Yes
☐ No

If yes, please explain why ______________________________

____

Q11. Does multimedia in the map make a difference?

☐ Yes
☐ No

If yes, please explain why ______________________________

____

Q12. Does your concept map help you understand better?

- ☐ Yes
- ☐ No

If yes, please explain why ______________________________

____

Q13. Creating my own map helped me to solve the problem?

☐ Agree ☐ Disagree

Q14. Concept maps make the subject more interesting?

☐ Agree ☐ Disagree

Q15. Using concept maps makes it quicker to solve a problem?

☐ Agree ☐ Disagree

Q16. You make mistakes with a concept map?

☐ Agree ☐ Disagree

Q17 Concept maps make you guess the answer?

☐ Agree ☐ Disagree

Section 3.

Q18 When you have to solve a maths problem please put the following steps you would take in the order you would do each step by writing a number before each step:

___ Estimate the answer
(roughly solve the problem in your head)

___ Read the problem
(to understand what is required)

___ Make a plan to solve the problem
(how many steps are required to solve the problem)

___ Visualise the problem

(draw the problem as a diagram or a picture)

___ Check
(check to make sure you are correct)

___ Put the problem in your own words
(make sure you understand what you have to do)

___ Do the required maths
(do all of the operations in the correct order)

Worksheet 1

Simplify the Equations for the Variable *y.*

In other words:

$-12x = 3(y - 3)$

$6(-16x - 8) = 24y - 120$

$6(-5x - 16) = -30y + 84$

$3(16x - y) = 39$

$3(5x - 5y) = 60$

$6(19 - 9x) = 18y + 96$

What would you use from the Mathematics Toolkit in a concept map to show others how to solve these problems?

Worksheet 2.

1) Solve the equation $3y - 6 = 9$ to find a solution for the variable y. Then substitute the value you found for y into the original equation to check that you have an identity. Show your work.

2) Look at this equation $5w + 5 = 2w - 4$.
   Described the steps you would take to isolate the variable.

3) An archaeologist and crew are beginning and excavation of some ancient ruins. The excavation site is the shape of a 12 m by 15 m rectangle. The crew examines approximately 10 square metres of the site each day.

   a. Write and algebraic expression for the area remaining to be excavated after X day's work
   b. Will the archaeologists work be finished after 14 days?

Remember, show the steps you would take to create a concept map to solve this problem.