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Cognitive Load Theory and the Teaching of Complex Concepts in Senior Secondary School Chemistry Curriculum: The Place of Element Interactivity

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Abstract
In the effort to develop a procedural guide for teachers on effective delivery of instructional contents, this study used a conventional lesson note on electrolysis for SS2 Chemistry students to derive examples of the facts, concepts, processes, procedures and principles of learning matter, being the content type elements of knowledge embedded in the concept of electrolysis. These elements were used to explain the interactions that take place amongst the elements of a complex learning matter. The study also highlighted the components of cognitive load which arise to hinder or facilitate meaning making, based on the level of interactivity of the elements and the background knowledge of a learner. To achieve the objectives of instruction, teachers are encouraged to ensure that learners comprehend the interacting elements of learning matter individually before presenting chunks of same for the achievement of the target learning outcomes.

Keywords: Cognitive load, Interactivity, Electrolysis, Chunking, Chemistry Curriculum

Introduction

In the quest for industrialisation, the Nigerian nation has applied different educational policies to encourage the study of science courses in secondary schools and science disciplines in higher educational institutions. The policies have also emphasised credit level passes in Mathematics and science subjects in WAEC and NECO examinations for candidates to be admitted into science and technology disciplines in Nigerian ivory towers. But the performances of secondary school leavers in Chemistry, Biology, Physics and Mathematics have remained below expectation (Olojo et al., 2022). Even amidst adjustments in content delivery strategies informed by feedback from examiners' reports, the failure rate in science subjects remains unabated. Analysis of the WAEC examiner's report in Chemistry revealed that students actually lack the requisite knowledge of the content in critical aspects of the Chemistry syllabus (Olojo et al., 2022). A pilot survey of the teaching components as implemented in a few public secondary schools in Port Harcourt metropolis indicates that:

i) Chemistry teachers are duly qualified and experienced
ii) The teachers actually taught the content as specified in the curriculum and scheme of work
iii) Adequate number of lessons were planned and delivered to the students based on the nature of the content``
iv) The lecture method, classroom discussion, demonstrations and practice sessions were duly utilised in delivery of classroom and laboratory instructions as appropriate
v) Classroom lecture sessions also incorporated instructional media where available.

Ordinarily, it could be assumed that such an effective teaching environment would achieve the objectives of the lessons and duly equip the students with mastery of content to excel in external examinations. The inability of the students to achieve the objectives of instruction, as evidenced in the Chief examiner's report therefore questions the effectiveness of the teaching methods and strategies of instructional delivery adopted in the teaching/learning

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of Chemistry concepts in the respective schools. One aspect of the Chemistry curriculum where deficient learner achievement has reoccurred consistently is the concept of electrolysis. A task analysis of the content of this concept in the curriculum and scheme of work of the senior secondary class reveals that electrolysis is a complex learning matter. By the implication of the attribute of complexity of learning matter, the learner must comprehend the individual elements that constitute the learning matter as well as combinations of the elements. By facilitating interaction among the elements or combinations of elements, prerequisite knowledge to the learning matter could then be generated as to enable the mastery of the main content. This facilitation of interaction amongst the elements of a learning matter is known as chunking.

Reasoning that learning, which is the process of acquisition of knowledge and skill, "is an intentional activity when it happens through purposefully arranged information, human resources and environment to achieve certain purpose", Branch (2009) identified the presence of student, content, media, teacher, peers, time, goal and context in intentional learning. Even content alone is complex because "it is a constituent of concepts, rules, propositions, procedures and socially constructed information" (Branch, 2009). Complexity is therefore an inherent attribute of any purposeful learning matter. But if a learning task is too complex, learning can be marred because of the high element interactivity associated with complex learning matter. More so, the working memory of the learner which can process a limited amount of new information at a given time could be overloaded, having been subjected to processing high element interactivity learning matter (Clark & Mayer, 2008). This is the corner stone of the theory of cognitive load. It is in this vein that William observed that Sweller (1988) theory of cognitive load is "the single most important factor that guides a teacher in design and effective delivery of instruction". To bypass the limitations of the working memory and facilitate learning, the principle of element interactivity is used to present learning matter in chunks. The process of chunking involves the activation of schemata; an attribute of expertise in the particular subject matter. This is a process whereby numerous information elements of the learning matter interact to activate prerequisite knowledge which then reduces the load on working memory thereby facilitating automatic processing of learning matter. It is in this vein that Ngu et al. (2023) noted that "an increase in expertise allows the learner to incorporate interconnected elements into a schema, thus reducing the level of element interactivity".

Therefore, element interactivity of a learning matter is expertise dependent. The subject matter expert whose schemata are highly developed will experience low element interactivity in processing the said learning matter and low level of cognitive load. But the novice will face higher cognitive load arising from high element interactivity of the learning matter. The major concern of the teacher or instructional designer is to develop learner schemata in order to reduce cognitive load and facilitate mastery of content. The severity of the load increases and reduces in accordance with the level of required interactivity of the elements that make up the learning matter By the structure and provisions of the Nigerian secondary education curricula, an SS2 student of Chemistry should be conversant with the concept of electrolysis and be able to set up laboratory facilities to conduct practical demonstrative experiment of the process of electrolysis. Electrolysis is "the chemical decomposition of compound brought about by a direct current passing through either a solution of the compound or molten compound" (Bajah et al., 2000). The concept of electrolysis evidences the structure of a complex learning matter. The different stages of procedural activities in electrolysis and the elements of information are indicative of complexity of content and high element interactivity in the processing of the learning matter. This complexity is also noticeable in the graphic objects used by the teacher to illustrate the relationship of the anode and cathode as well as the behaviour of ions in the electrolyte.

The target learning objectives as specified in SS2 Chemistry curricula include:

i) Knowledge of the products of electrolysis
ii) Ability to calculate the quantity of electricity consumed in a chemical reaction
iii) Ability to describe the structure of electrolytic cell
iv) Ability to state Faraday's law of electrolysis and the process of its verification
v) Ability to explain the process of electrolysis and state the associated chemical equation

The study hereby adopted one of the instructional objectives, ie To develop learners' ability to explain the process of electrolysis and the associated chemical equations.

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Presenting the cognitive theory of multimedia learning, Mayer (2005) made reference to Paivio (1971) dual code theory of information processing; noting that learning is effective when both human sensory channels for imagery and verbal information are engaged. The dual code theory holds that the learning process integrates the words and picture content of a lesson into a unified structure and stores same in the long term memory after making the requisite meaning. The processing activity is undertaken within the limited capacity of the working memory. If the capacity of the working memory is exhausted with processing activities, the learner gets frustrated and fails to make the requisite meaning of the instructional matter because the capacity of the memory to hold information and process same simultaneously had been exceeded. In summary, when an instructional activity overloads the processing capacity of the working memory, learning becomes difficult because undue burden has been placed on the meaning making process. Clark and Mayer (2008) referred to this burden on the working memory as cognitive load. Cognitive load theory (CLT) specifies three distinct categories of cognitive load (Sweller et al., 2019). They are the intrinsic, extraneous and germane cognitive loads Every instructional matter has associated inevitable cognitive load that the learner must undertake in order to process the instructional content and make the requisite meaning. This is referred to as intrinsic cognitive load. But if the burden (cognitive load) derives from errors in the design and delivery of the learning matter, then it is an extraneous type of cognitive load. To the novice learner, the intrinsic cognitive load may be so high that learning cannot take place. Then there arises the need to present another learning matter that would expand the learner's background knowledge concerning the subject matter and constitute anchorage for the new content. The burden associated with this additional learning matter is germane cognitive load. Germane cognitive load therefore derives from the germane cognitive content designed into a learning matter to alleviate the effects of intrinsic cognitive load.

Cognitive load however becomes significant and injurious to learning only when the processing requirements for instructional information exceeds the 7 ± 2 information elements working memory processing capacity for learning (Kester et al., 2010). This processing involves the interaction of information elements. Clark (2007) noted that these information elements are presented in form of facts, concepts, processes, procedures and principles which he referred to as content type elements of knowledge. Facts refer to specific information while concepts are generalised information about objects that possess certain attributes. While these two content elements may not require much processing interaction on themselves, the processing of the other types of elements i.e. processes, procedures and principles would require holding more information sub elements in the working memory while processing the learning matter (Chen et al., 2023). Sometimes however, the instructional matter requires the processing of combinations of facts, concepts and principles at the same time in order to make the requisite meaning of the learning matter. At such moment, which is usually associated with complex concepts, the working memory capacity of the novice learner would obviously be exceeded and the cognitive load would be so substantial that learning may be impeded because the high element interactivity requirements of the learning matter exceeds the capacity of the working memory of the learner for the specific subject matter. Element interactivity is therefore the corner stone of cognitive load consideration in the design of instructional and training programmes. Clark (2007) elements of knowledge present the different types of definite knowledge elements that could be contained in a learning matter. As a meaningful subject content, each element can be stored in the long - term memory as a schema. In this vein, a single element of knowledge, e.g. fact that conveys a definite meaning, constitutes a schema. If multiple elements are brought together to convey a definite meaning, they also constitute a single element as well as a schema. The difference however is that while the one element schema, e.g. fact is low in interactivity and cognitive load, the multiple element schema is fraught with high element interactivity and high cognitive load in the process of meaning making for the specified level of learner. Some complex learning materials also require combination of facts, procedure and principles to convey intended meaning to the learner. Such a case presents high cognitive load to the learner because of the high element interactivity involved in meaning making.

In planning the lesson on electrolysis with the objective to equip SS2 Chemistry students with the ability to explain the process of electrolysis, the learner should be able to:

1) Provide factual knowledge of the different components required for the experiment
2) Identify the chemical composition of the different types of solvents
3) Explain the actions that activate the process of discharge and the movement of anions and cations
4) Highlight the procedural do steps for set up of the electrolysis experiment
5) Discuss the procedure for composing the electrolytes with appropriate measures of the respective chemical substances

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6) Explain the interactions that take place amongst chemical substances during decomposition or chemical reactions as well as the impact of electricity on the conducting elements of the liquefied chemical substances.

Cognitive load and element interactivity

One major attribute of complex concepts is that they are difficult for learners to comprehend because they are made up of a number of content elements and all the elements are required to interact simultaneously in order to facilitate meaning making. High element interactivity is therefore a ready attribute of complex concepts. Sweller observed in Spector et al. (2009) that, “high element interactivity results to high intrinsic cognitive load, leaving little memory capacity for learning”. Advocating the “isolated interacting elements effect”, Pollock et al., (2002) noted that “empirical works support the initial teaching of individual elements, though at the risk of not achieving the overall learning objective, followed by interaction of the elements”. By this approach, more effective learning is achieved rather than subjecting the learner to high element interactivity learning materials abinitio. And in what Foshay (2010) classified as types of declarative knowledge; facts, concepts and principles must not always be taught as isolated elements of knowledge, but presented collectively in the “appropriate mental model” for optimum structure of information to enable the learner store, retrieve and apply knowledge in accordance with need. Foshay (ibid) further explained that mental models are “networks of principles along with their supporting concepts and facts stored in meaningful structures based on:

a) The context of the specific subject for which it was created.
b) The past learning experiences or background knowledge of the learner,

The instructional activity is therefore an effort at enabling the learner develop the mental model for learning and application of given knowledge. In the absence of adequate level of background knowledge, the learner would not be able to process the network of facts, concepts and principles within the specified subject matter and learning would be impaired. This is because the working memory is limited in the level of element interactivity permissible at the given level of background knowledge. There is therefore the need to process the elements of declarative knowledge individually. Incidentally however, such individual processing (learning) of the elements of knowledge cannot facilitate the achievement of the overall learning outcome (Pollock et al, 2002). The learner would then have to process (learn) combinations or chunks of the elements. At the final stage, the network of facts, concepts and principles are processed collectively. At this stage, the processing of individual elements and chunks of same would have guaranteed enough background knowledge to facilitate overall success of the learning effort and the achievement of the target learning objectives. In the lesson on electrolysis, which sought to develop learners' ability to explain the process of electrolysis, the concern of cognitive load considerations hereby prompts the teacher to review the following factual information in the concept of electrolysis:

- Cathode, Anode, Sodium, Ions, Cations, Anions,

And the following concepts:

- Electrode, Electrolyte, oxidation,

Then procedures:

- Oxidation, conductivity of solvent

Then process

- Movement of ions and

Principle

- Electrolysis

Next is the use of chunking for combinations of elements that collectively communicate a given content. Concerning the chunking of knowledge matter, Foshay (2010) observed that “memories are stored, not as

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individual bits or as long strings of information but in chunks of learning matter which contain seven elements". Meaningful chunks of learning matter are therefore developed, using combinations of relevant facts, concepts and principles. Finally, the different chunks of memorable learning matter are collectively presented to the learner to facilitate the achievement of the target learning outcomes based on established basic knowledge.

Justification

There is no gainsaying the fact that many teachers present instructional matter to students without due attention to the limited processing capacity of the working memory. Most times, teachers rely on the generalised assumption that learners would recall the related learning matter as treated in previous lessons. But in reality, most learners manage to muster faint understanding of concepts and memorise subsequent explanations without adequate comprehension of concepts. The students eventually lack the ability to define concepts in their own words or undertake due discussion of same. Consequently, they are ill equipped to apply the concept into problem solving purposes. By identifying the content elements of a given learning matter as well as the sub elements that interact to produce the different elements that make up the concept under study, a teacher is able to design and develop instructional matter around the sub elements and chunks of same. By this teaching approach, the teacher is able to create rich knowledge base that grants the learner the capacity to process and internalise the new knowledge. Actually, the demands of instructional planning and class duration regulations may not accommodate digressions in the delivery of criterion content for the purpose of creating background knowledge. The gain in overall achievement of learning objectives underscores the need for the learner to undertake such germane cognitive tasks. This study hereby presents skills - based approach to cognitive load considerations in procedural presentation of complex learning matter using the concept of electrolysis in senior secondary school Chemistry curriculum.

Aim and Objectives of the study

The study aims at demonstrating the process of element interactivity and chunking as mechanisms for management of cognitive load in instructional activities

Objective of study: The objectives of the study were to;

1) identify the content type elements of knowledge and the appropriate teaching strategies for the facts, concepts, processes, procedures and principles in the concept of electrolysis
2) ascertain the procedure for the chunking of content elements of electrolysis for Senior Secondary Two chemistry students.

Discussion

Content Type Elements of Knowledge and the Respective Teaching Strategies

The items of declarative knowledge in electrolysis consist of a range of elements and sub elements of knowledge that interact to communicate specified information to learners. They are classified as facts, concepts, processes, procedures and principles

Facts: Factual element of knowledge in electrolysis is the basic components of the concept of electrolysis. Examples include: Cathode, Anode, ions, cations, anions, electromotive force (emf) etc. In teaching the lesson on electrolysis, the teacher adopts appropriate teaching strategies, choose the requisite media object to elucidate the content of learning matter and also evaluates the lesson to ascertain the extent to which the learner has achieved the target learning objectives. Using the lecture method and pictorial graphics, the teacher explains knowledge level factual information to the learners on the objects, ideas, actions, etc. that constitute the basic components of electrolysis. The graphic objects also present pictures of the electrolytes and individual pictures of the cathode, anode, ions, cations, as well as the emf. In lesson evaluation, the teacher assesses learners' ability to recall and identify these constituents of electrolysis.

Concept: A concept is made up of facts. It is a class of objects, events, ideas or actions that can be grouped together on the basis of shared attributes. Examples of concepts in electrolysis include electrode, electrolyte, solvents, etc. The use of graphic media objects in the lecture method can facilitate comprehension level teaching of concepts. The teacher has to present the critical attributes of the concept with its examples and non examples. The assessment of concept tests students' ability to define the concept in their own words and recognise examples of the concept based on the attributes.

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Process: The process is a description of "how things work". Examples of process in electrolysis include the discharge and movement of cations and anions. A graphic simulation of the process is most appropriate to facilitate learners' comprehension of the content. Learners understanding can be ascertained by asking the learners to describe the process.

Procedure: The sequential tasks performed in a series of clearly defined steps that result to achievement of a given job task is a procedure. An example is the set - up and activation of the electrolysis experiment. The teaching method for procedure is the demonstration method. The learner shall also be exposed to scaffolding or practice of the practical steps in the learning experience. Assessment is by tasking the learner to perform the said task of set up and activation of the electrolysis experiment. Learner achievement score is based on weighted scores of learner performance on the different aspects of the experiment.

Principles: The principle is an underlying scientific statement of the relationship of two or more concepts. It is evidenced in the decomposition of the chemical elements in electrolysis. It is also revealed in the effect of electromotive force (emf) on the conducting elements of an electrolytic solution. Principle can be taught deductively by describing how a general statement of a relationship can apply to specific supportive instance. It can also be taught inductively whereby the process of its evidence supports a conclusion. The evaluation of principles lesson would have students present the relationship of concepts in their own words, site instances of application and also predict the effects of the application.

The interacting elements of knowledge and the chunks of learning matter that control cognitive load and facilitate the learning of the concept of electrolysis.

The presentation of separate segments of lessons to students on the different content type elements of electrolysis cannot enable them comprehend the concept of electrolysis as to be able to provide holistic explanation of the concept. There is therefore the need to bring together, multiple elements and multiples of sub elements of knowledge matter on electrolysis as to facilitate learner construction of requisite knowledge based on the already established background knowledge. This is the chunking mechanism in the design of instruction. Examples of this need in the concept of electrolysis include:

i) The activities and chemical reactions at the anode
ii) Activities and chemical reactions at the cathode
iii) The factors that affect preferential discharge of ions in electrolysis

These are essential knowledge that the learner requires to be able to explain the concept of electrolysis. But each of these components of knowledge consists of more than one content element. An example is the knowledge of the reaction at the cathode which is facilitated by knowledge of the concept of electrode, electrolyte, emf, the discharge of ions, etc. Knowledge of the chemical reactions at the cathode is therefore a new understanding that depends on afore mentioned elements of knowledge for effective mastery. The teacher is therefore obliged to present the collection of content elements and sub elements that facilitate the understanding of a given chunk of learning matter in electrolysis before combining all the other parts for a holistic comprehension of the concept of electrolysis.

Conclusion

Target learning impact is most cogently realised when an instructional intervention is structured to align with the natural process of human learning. This is especially as it relates to the assimilative and accommodative constructivist activities and the content interactivity mechanism of the working memory. It also considers the limitations in the processing capacity of the working memory. But amidst the considerations of memory capacity limitations in the design of instructional interventions, learners still experience learning difficulties and impediments in the flow of understanding of subject matter as a result of variations in students' background knowledge of the subject matter. This impediment arises from:

iv) The effort of the learner to make meaning of the subject matter when he/she lacks adequate background knowledge for it.
v) The existence of extraneous design content in the instructional intervention.

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It is therefore the view of this study that the establishment of adequate background knowledge of subject matter for given set of learners, would constitute anchorage for flow of understanding that is inherently motivating (Kiili, 2005) This flow state in learning would dwindle the impact of any extraneous design and facilitate the achievement of learning objectives.

Suggestions

1. One obvious defect of the interactivity and cognitive load considerations in design and delivery of instructional tasks is that the average classroom lesson period for secondary education programmes is inadequate for effective delivery of new knowledge matter alongside the germane instructional tasks required to anchor it. Teachers' inability to undertake the extended teaching tasks advocated in the "germane instructional model" can therefore be inadvertently hinged on the need to adhere to class duration regulations. This regulation is however at variance with the extended time on classroom tasks required by this teaching model. It is hereby suggested that the blended teaching approach should be adopted in delivery of instruction at the secondary school level of education.
2. The blended mode of instruction may be structured as face to face teaching session organised as formal lesson and a complementary tutorial session. It can also be structured as face to face lessons with technology facilitated complimentary teaching session. The teacher may wish to use the complimentary session to present the elements of knowledge that interact to develop the background knowledge prior to the formal lesson. The main lesson shall then present the new content using chunks of the elements of knowledge already treated in the complimentary teaching/learning session. By this approach, learning gains would be achieved within the limits of classroom lesson - period regulations.

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