Using cognitive load theory to help students learn more effectively

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Psychologists distinguish between two types of memory

- Limited capacity primary memory (“working memory”)
- Unlimited capacity secondary memory (“long term memory”)

“Learning” is the process of transfer of new information from working memory to long term memory, typically by associating it with some existing prior knowledge

Hence working memory is of interest when thinking about learning
Fig. 1. A model of learning and memory organisation in information processing.

“Limited capacity”


Cognitive Load Theory

Load imposed by learning

Load imposed by learning materials

Working memory ‘space’

- Germaine load is related to the efforts involved in learning.
- Extraneous load is related to the manner in which material is presented.
- Intrinsic load is related to the inherent difficulty of the material.

Intrinsic Load: Difficulty of route
Extraneous Load: Quality of Directions
Germane Load: Actions to get to destination
“Measuring” cognitive load

• Performance
  • *E.g. Stroop Test “Yellow”*

• Subjective
  • *E. g. Users rate the difficulty of a task*

• Physiological
  • *E.g. Eyes (dilation, blink rate), heart rate, sweat*
Cognitive Load and Multimedia

Richard E. Mayer, Multimedia Learning, Cambridge University Press, 2009
Table 3: Correlation matrix showing inter-correlation for all variables in the study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PK</th>
<th>Y1</th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAO</td>
<td>0.746**</td>
<td>0.366**</td>
<td>0.205</td>
<td>0.337**</td>
</tr>
<tr>
<td>PK</td>
<td></td>
<td>0.592**</td>
<td>0.529**</td>
<td>0.611**</td>
</tr>
<tr>
<td>Y1</td>
<td></td>
<td></td>
<td>0.654**</td>
<td>0.684**</td>
</tr>
<tr>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* CAO = CAO points, PK = Prior knowledge, S1 = semester 1 test score, S2 = semester 2 test score.
* SRI and SRS = student-rated attendance, interest and level of study respectively.
* No correlation in second and subsequent years.

No correlation in second and subsequent years.
Chemical education research—facts, findings and consequences

A H Johnstone

The 1960s saw the advent of a rash of curricular changes in chemistry in much of the English speaking world. Chem Study and Chem Bond appeared in the US. Nuffield became the trend setter in England and Wales and was exported to several parts of the world. In Scotland, the Chemistry Conservation Society was established in 1962 and was rapidly adopted in all schools. Several curricular packages were tried, with varying success, in Australia and New Zealand and some of their new thinking found its way into Britain.

All of these changes have brought in their wake, feelings of dissatisfaction and those who are averse to these attempts to revise them. Some find the activity taking place on an emotive rather than rational grounds. ‘Back to Basics’ has become a slogan no more meaningful, but names potent as ‘Power to the People’.

Ten years ago a research team was set up in Glasgow to examine the Scottish Attitudes to Science and its effects upon schools, pupils, employers and Higher Education. We were aware that all was not well, and measured the research was necessary. It was decided to begin the inboxes which would select and eliminate the student information in which the students were asked about. Ten student was invited to choose from the topics which they had read in school, those with which they still had difficulty and would like to be resolved. The results obtained from different universities and over a period of two years showed an unacceptable quantity of the students.

When we came to investigate the other areas of the text, the hypothesis was that the orientation of a formula was important. To write an ionic equation, it is customary to present either the side or the structural formula “battlements” to facilitate the ‘tops operation’ for the elimination of water. This hypothesis was shown to be untenable, but gave us the first clue to the biochemistry of organic chemistry and eventually to its biochemistry in several other areas.

It was clear that the problem lay somewhere in the students’ perception of the organic chemical requirements. To achieve this, we decided to use the students’ short term memory. When asked to prepare a formula, they could easily recall it in the next 10 seconds. If the sequential increases to 12 letters, such as AQR/FR/LE, few people can recall them. However, another 12 letter sequence can be easily recalled if it it of the form, BUOCT/NALR/W, because English speakers perceive it as four short words. This is in line with the psychological observation that most people can store between seven and nine pieces of information in short term memory. The size of the memory depends upon the nature of the task and the way it is presented to the problems. This way it is presented by the problems.

The main areas which seemed to be raising the problems were:

(a) Energetics—including Hess’s Law, $E^\ddagger$’s and cells;

(b) Stoichiometry—writing and balancing equations, ionic equations, ion-electron half equations, moles in solution;

(c) Organic—particularly esterification, hydrolysis, condensation, saponification, carbonyl compounds.

The University of Edinburgh
School of Chemistry

Chemistry in Britain, 1981, 17, 130-135
See also Chemical Society Reviews, 1980, 9, 365.
Pre-lecture resources

Welcome to the Pre-Lecture Resource
CHEM1306 Lecture 1

Before you begin:
Slides with the audio symbol in this resource require audio output. Headphones can be borrowed from the library. You will also need to have a periodic table for the quiz. This can be found at the back of any chemistry textbook.

When you are ready:
Click the next button below or the Aim tab to go to Aim.

You can navigate using the tabs or the menu on the left hand side.
Flipped learning in higher education chemistry: emerging trends and potential directions

Michael K. Seery

Flipped learning has grown in popularity in recent years as a mechanism of incorporating an active learning environment in classrooms and lecture halls. There has been an increasing number of reports for flipped learning in chemistry at higher education institutions. The purpose of this review is to survey
Extraneous load

Corresponding Example from Control Laboratory Manual.

1. Obtain four clean, dry test tubes. Pour 1.0 mL samples of sodium thiosulfate solution ($Na_2S_2O_3$) into the tubes as follows:

   - Tube 1: 0.25 M $Na_2S_2O_3$
   - Tube 2: 0.50 M $Na_2S_2O_3$
   - Tube 3: 1.0 M $Na_2S_2O_3$
   - Tube 4: 2.0 M $Na_2S_2O_3$

2. Add 1.0 mL 2.0 M hydrochloric acid (HCl) to Tube 1. Record the initial time when mixed together and the final time when the first cloudiness appears in the test tube. Calculate the total reaction time.

Example from Experimental Laboratory Manual

1. 1.0 mL $Na_2S_2O_3$ with concentration
   
<table>
<thead>
<tr>
<th>Concentration</th>
<th>0.25 M</th>
<th>0.50 M</th>
<th>1.0 M</th>
<th>2.0 M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

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Example from Experimental Laboratory Manual

“significantly higher scores on measures of achievement and psychomotor skills, and also stimulated students to develop more favorable attitudes toward the laboratory activities”

“Fewer practical related questions in the (school) lab”


<table>
<thead>
<tr>
<th>Coherence Principle</th>
<th>Signalling Principle</th>
<th>Redundancy Principle</th>
<th>Contiguity Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclude interesting but irrelevant material as this material reduces cognitive capacity to process essential material in a lesson.</td>
<td>Include vocal cues and/or visual highlights to aid the selection and organisation of important information, especially for learners with low prior knowledge.</td>
<td>Graphics with narration alone is more effective than also including on-screen text. Adding one or two keywords as on-screen text has benefit.</td>
<td>Place printed words near any corresponding graphics, and coincide narration with related display.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Segmenting Principle</th>
<th>Pre-training Principle</th>
<th>Modality Principle</th>
<th>Embodiment Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add self-pacing options to enable learners to process information before continuing.</td>
<td>Provide option to view information on key terms to allow learners to familiarise before having to work with them.</td>
<td>Present information about a graphic verbally rather than as text so that learners can listen and refer to graphic, especially for system paced dynamic graphics (e.g. videos).</td>
<td>Drawing graphics as you explain is more beneficial than explaining a presented drawing as it reflects a real-life social interaction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Personalization Principle</th>
<th>Voice Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present words in conversational style rather than formal style, including the use of personal pronouns (I and you) in script, especially in early stages.</td>
<td>Narration should use a human voice rather than a computer voice, and this should match any on screen voice character.</td>
</tr>
</tbody>
</table>

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## Germane Load

Worked examples aim to change the focus of mental effort away from solving a particular problem to learning how to solve a problem of a particular type.

<table>
<thead>
<tr>
<th>Example</th>
<th>Worked Example</th>
<th>Fading</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>An example outlines the overall approach to solving a particular problem.</td>
<td>A worked example identifies the particular steps (sub goals) involved in solving a problem.</td>
<td>Fading involves requiring learners to focus on one particular sub goal in iterative versions of a problem.</td>
<td>A problem is one where learners need to use known sub goals to arrive at a solution.</td>
</tr>
</tbody>
</table>

Worked examples

Typical quiz

Rank the following in order of increasing (weakest to strongest) conjugate base strength: $\text{F}^-; \text{I}^-; \text{Cl}^-$

Worked example quiz

Stage 1:
Full answer showing stages for solving problem:
1. Identifying acids
2. Arrange acids in order of strength
3. Identify and rank conjugate base strength

Stage 2:
Answer shows stage 1 and stage 2:
1. Identifying acids
2. Arrange acids in order of strength

Stage 3:
Answer shows stage 1:
1. Identifying acids
Student completes stage 2 and stage 3
2. Arrange acids in order of strength
3. Identify and rank conjugate base strength

Stage 4:
Student asked question only:
Rank the following in order of increasing (weakest to strongest) conjugate base strength: $\text{F}^-; \text{I}^-; \text{Cl}^-$
Moving On #1

Thinking more broadly about learning scenarios with a cognitive load perspective
What knowledge do students draw upon for application?
Formative Assessment (Sadler)

Students must develop the capacity to monitor the quality of their own work during actual production.

- Possess a concept of the standard being aimed for
- Compare the actual level of performance with the standard
- Engage in appropriate action which leads to some closure of the gap

Changing the feedback model

“Loading up” feedback
Hendry 2013


Here is my best effort
Grade work against (assumed) standard

This is the standard

This is the standard (exemplar)
Guidance

Here is my best effort
Grade work against (stated) standard
Students watch **EXEMPLAR** materials such as video in advance of their lab class.

**ASSESSMENT** begins in the lab. Students video each other as they demonstrate the technique. Then they peer review.

Students **SUBMIT** their video for review by instructor to confirm competency is demonstrated.
It is not uncommon in undergraduate laboratories to see students working as fast as possible just to get finished, with little or no thought about what they are doing.

Beyond a simple cognitive load framework

Experimental technique

Theory

Recognizing apparatus

Experimental outputs

Lab book recording

Handling protocols

Lab routines

Written instructions

Safety procedures

Verbal instructions

Beyond a simple cognitive load framework
Complex Learning Framework*

Complex learning
(i) aims at the integration of knowledge, skills, and attitudes.
(ii) involves the coordination of qualitatively different constituent skills.
(iii) requires the transfer of what is learned to real settings.

Supporting Learning in a Complex Environment
A focus on whole-tasks rather than part-tasks
Simple to complex sequencing

Information needed to work in a Complex Environment
Supportive information
Procedural Information

A Survey of Pre-Laboratory Literature

**Kempa, BJET, 1974**
- Video-taped demonstrations

**Krakower, JCE, 1977**
- Lap-dissolved slides

**Moore, JCE, 1980**
- Simulations

**Kolodny, JCE, 1983**
- Quizzes

**Isom JRST, 1986**
- Pre-lab discussion

**Limniou, CERP, 2007**
- Simulations for experimental design

**Gallardo-Williams, JCE, 2017**
- Student generated videos

**Chittleborough, JCE, 2007**
- Quizzes with personalised feedback

**Winberg, JRST, 2007**
- Simulations prompting cognitive focus

**Cole, CERP, 2017**
- Videos for advanced labs

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**Complex Learning Framework**

**Complex learning**
(i) aims at the integration of knowledge, skills, and attitudes.
(ii) involves the coördination of qualitatively different constituent skills.
(iii) requires the transfer of what is learned to real settings.

**Supporting Learning in a Complex Environment**
- A focus on whole-tasks rather than part-tasks
- Simple to complex sequencing

**Information needed to work in a Complex Environment**
- Supportive information
- Procedural Information

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Moving on #2

Students are human beings
## Literature review: synopsis of benefits

<table>
<thead>
<tr>
<th>Category</th>
<th>Summary finding: Pre-laboratory activity tends</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall</strong></td>
<td>to have a positive impact on learning in the laboratory.</td>
</tr>
</tbody>
</table>
| **Experimental** | to increase the work requirements of students outside of formal class time  
                      | to increase the efficiency of students’ lab work  
                      | to result in students reserving questions for more complex techniques  
                      | to lead to fewer experimental errors  
                      | to result in improved understanding and efficiency of laboratory tasks, especially when students are prompted to consider overall approaches rather than stepwise instructions |
| **Conceptual** | to result in students discussing conceptual aspects more or feeling better informed about conceptual aspects.  
                       | to result in students performing better in the laboratory.  
                       | to lead students to feeling more autonomous about completing their laboratory work. |
| **Affective** | to enable students to feel more confident about laboratory work, and/or reduced student anxiety about knowing what to do during their practical session.  
                        | to motivate students about doing practical work, although there may need to be an extrinsic driver (such as assessment reward) to complete these activities. |

Discussion suggestions

• Are there problems just thinking about “bits of information”?

• Is it too utilitarian? Isn’t learning richer than this?!

• Application beyond chemistry/sciences?

• Limitations of CLT (not a theory(!), not summative)?