# Effect of scaffolding tools on Biochemistry students

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***Abstract***
*This paper evaluated the effect of two scaffolding tools, Advanced Organization Tool (AOT) and Higher-Order Thinking Tool (HOTT) in a flipped classroom experience in a University course in Namibia. Scaffolding tools can be used to improve science students' transfer level and knowledge retention among university students. Four groups of students were compared: 1) AOT group; 2) HOTT, and 3) the combination of AOT/HOTT and 4) the control group. The study shows that the scaffolding tools were particularly effective concerning retention. No significant differences between groups were found on the students' transfer scores. Moreover, even if there was no clear significant difference, the use of multiple tools in the same groups seemed to impact negatively students' performances. The primary idea for this study was to test the effectiveness of the scaffolding tools in enhancing natural science education. The current study was on a small group scale therefore the findings are specific to the target group and could not draw a general conclusion for all branches of natural science (Physics, Chemistry and Biology). The researchers recommend a more inclusive and prolonged study to make a more comprehensive conclusion and give enough time to test the reliability and validity of the tools as well as the effects of scaffolding as far as retention and knowledge transfer are concerned.*

**Keywords:** *analogical, scaffolding tools, transfer, higher-order thinking, retention, biochemistry*

## Introduction

Numerous universities around the globe are developing and supporting ways of improving students' academic success (McCallum et al., 2015). This success largely depends on the students' motivation to engage in their studies and hence novel teaching approaches should be more student-centered rather than the traditional lecturer - centered approach (Bodner & Orgill, 2004; Brush & Saye, 2002). The idea is to foster students' engagement and involvement which in turn helps them to develop higher-order thinking and critical problem-solving skills (Brush & Saye, 2002; Bliss et al., 1996; Wilson & Devereux, 2014). The significant growth in technologies today gives many educators concern on how to engage and take full advantage of the instructional media to provide more effective student-centered instructions (Giannakos et al., 2015). Familiar technologies including social media such as "Wiki", "Facebook", "You-tube" and "WhatsApp" gained much attention for information exchange, collaborations, instruction and interaction with the course materials (Giannakos et al., 2015). The use of digital videos in education has been widely studied and employed in recent years as one of the powerful tools for dissemination of information in education (Barrett et al., 2009; Copley, 2007; Giannakos et al., 2015) and it has been applied in a variety of ways such as online courses and flipped classroom (Giannakos et al., 2015).

## Literature review

Flipped classroom model is a pedagogical method in which the content and material are delivered primarily outside the classroom environment, using online tools and educational technologies, while in-class time is used for hand–on activities, elaboration on advance concepts, active learning through advanced problem solving and student collaboration (Lockwood & Esselstein, 2013; Galway et al., 2015; Jiang et al., 2020). In this way, class time can be used for active student-students and students-educators' collaborations allowing more possibilities for advanced problems solving activities (Lockwood & Esselstein, 2013). Although flipped classroom is just gaining popularity mostly in southern African countries, benefits such as self-paced learning, students' engagement, increasing student-teacher interaction and more comprehensive feedback have been well documented (Nana-Sinkam, 2014; Goodwin & Miller, 2013; Roehl et al., 2013; Sadaghiani, 2012). Hence, the flipped classroom model provides a well understood environment to investigate the effects of scaffolding tools on students' knowledge transfer and retention.

In the current study, two different scaffolding tools were assessed: prompt cards as a Higher Order Thinking Tool (HOTT) and analogies as Advanced Organisation Tool (AOT). In educational context, a scaffold is referred to as a temporary framework to support learners when assistance is needed and is removed when no longer needed (Lajoie, 2005; Puntambekar, 2022). Scaffolding metaphor was delivered from the socioconstructivist model of learning (Puntambekar & Kolodner, 2005; Lajoie, 2005; Brush & Saye, 2002) and Jerome Bruner (1976) extended the term to describe the process in which a child or novice could be assisted to achieve a task that they may not be able to achieve if unassisted, until they are able to perform the task on their own. Vygotsky (1978) described the concept of Zone of Proximal Development (ZPD) as the distance between the noticeable developmental level where students can solve problems without any support, and the potential level where a student can only solve problems under guidance or else in collaboration with the more capable peers. Teachers and students tackle a learning situation with their own understanding, and shared meaning to thrive in their learning (Lajoie, 2005; Puntambekar & Kolodner, 2005). The support will then be later reduced and eventually removed in the process called fading. Fading occurs as students gain more independence and the support is no longer needed. They are now able to solve problems and complete tasks without the help of the teachers. In Bloom's Taxonomy of Learning, different levels of learning are categorized into two groups:

- Lower Order Thinking Skills (LOTS), comprising knowledge (remember), comprehension (understand) and application (apply); and
- Higher Order Thinking Skills (HOTS) including analysis, synthesis (create) and evaluation (Narayanan & Adithan, 2015).

Hence, HOTT was created based on the HOTS to enable students to create and evaluate their own understanding. Human cognition depends on the structure of information and the way it is organized. When information presented to students is well-structured, it enables the flow of information in their brain, from working memory to long term memory (Kirschner et al., 2006). Analogies can help students organise the new knowledge to form a scheme that can be easily processed from the working memory to the long-term memory. An analogy is defined as a comparison between two domains, the familiar domain (analogy) and the unfamiliar domain (target) (Else et al., 2003; Bodner & Orgill, 2004; Guerra-Ramos, 2011; Hernandez & Espitia, 2021). The AOT is based on analogies and was designed to support this process.

**Purpose of the study**

The current study aimed at investigating the Higher Order Thinking Skills and analogies as advanced organisation tool in a flipped classroom environment to enhance students' ability to transfer and retain information in the Bioenergetics and Metabolism classes. The study addressed the following research questions:

1. What is the effect of analogies as advanced organizers scaffolding tool on students' retention of the information (making connection with their existing knowledge and the new information or concept, therefore aiding in information transformation from short term memory to long term memory)?
2. How best can higher-order thinking tool assist students to transfer knowledge to become independent thinkers?
3. What is the effect of the combination of the two scaffolding tools on both transfer and retention?

The study sought to determine a mode which educators could use to lead students to be self-motivated, engaged and make them feel accountable for their own education. Thus, the study focused on scaffolding as a tool to proactively enhance students' understanding of natural science in a flipped classroom environment at institutional level.

**Research design**

To measure the effects of the crossed method (Flipped Classroom- Scaffolding model) a quasi-experimental design within the classrooms was used in a mixed method study.

The quantitative data were collected from the tests given to students after the study. The tests were composed of questions based on higher-order thinking. The qualitative data on the other hand were collected from the classroom field notes. There are numbers of scaffolding tools that one can choose from depending on what one wants to improve in their classes. In this study, the research focused on analogical scaffolding (for fostering student retention) and scaffolding for higher-order thinking by using prompt cards. In order to evaluate the efficiency of the scaffolding tools, the students were given a transfer test and a retention test. The transfer test was given to test the efficacy of the Higher Order Thinking Tool, while the retention test was given to measure the degree of learning by means of detecting students' information retention abilities.

***Participants***

Researchers used purposive sampling method in this study (Sale et a., 2002; Mack et al., 2005). The study was conducted at the University of Namibia Main campus, in the Department of Chemistry and Biochemistry. Seventy-Six (76) third year science students majoring in Chemistry, Biology and Biochemistry participated in the study. The students were then divided into 4 groups. The groups consisted of varied number of students ranging from 17 to 20. These groups covered the same topic, electron transport chain and phosphorylation under glucose metabolism as the general topic. Flipped classroom approach was applied to all the four classes throughout the study. The researchers conducted all the four classes at the same venue at different times over a week using different approaches.

***Data collection***

The class materials were posted on the online class portfolio three days prior to the class. Outside the classroom students accessed the provided videos via Google drive; these videos were accompanied by motivational questions based on the concept in the two videos. Students were expected to ask questions and comment on the lecture videos. In the classroom, the researchers addressed all the questions and comments posed by the students before giving them some scaffolding tools for the 3 groups (see Figures 1 & 2). Analogy is a more general way of identifying similarities between two different concepts, being structural or textual similarity, so both textual and structural analogies were provided for the same reason. Guerra-Ramos (2011) argues that when well explained and understood, analogies can facilitate transfer of basic structural information from the analogy to the target, thus creating intelligibility of new science material under study. Analogies can also help students with retention concepts that may look difficult to remember, enhancing student motivation, self-efficacy which enable them to learn science concepts. On the other hand, students were provided with higher order thinking tools to enhance the thinking ability. The ability to think critically is an important trait for every person, especially in today's world with complex issues; people must be able to make intelligent decisions and think critically. Hence, critical thinking must be the primary focus for higher education in order to provide the intellectual training for its students (Miri et al., 2007).

- The first group (AOT) was provided with some analogical problems that enabled students to make connections between what they knew better already and new information they were learning for enhanced retention.
- The second group (HOTT) was provided with a higher-order thinking tool by means of question card or prompt, composed of questions based on the topic, to engage students into thinking of higher order and to enhance student understanding to enable them to transfer what they learned from the lessons to other similar problems.
- The third group (HOTT/AOT) was provided with both question cards and analogies as scaffolding tools.
- The fourth group was a control group hence no tool was given, and all classes were flipped.

The data obtained from these groups were analysed with Statistical Package for Social Science (SPSS) software for variation using one-way Analysis of Variance (ANOVA). All the lessons were given in the same venue on different dates following the weekly timetable for the module under study. Each group was then allocated a 55 minutes' session between Monday and Thursday. Prior to the lesson, the researchers ensured that instructions were made clear to students. During the experimental classes, the support was given throughout to help students to remain focused and get the expected solution to the problems.

During the class session for higher order thinking tools (HOTT) group, questions were explained to the whole group first before extra support was lent to them in their respective groups. All students were asked to be free to ask and discuss the concept with their peers and the facilitator. They all worked in groups to foster student-student collaboration and made the session more interactive. The researchers monitored students' progress during the session to motivate them and to engage them into meaningful dialogues on the subject with their peers. At the end of each lesson, the researchers summarised the lesson and gave feedback to the whole group.

**Group 1: ECT Analogy**

1. The figure below is analogous to one of the process under the electron transport chain reaction; can you state the process/step and justify your answer?

**Answer:**..............................................................................................................

**Why that answer?**

..............................................................................................................

**Figure 1: Part of the Advanced Organization Tool (AOT)**

**Group 3: Scaffolding tool**

**Higher-order thinking tool (HOTT)**

**Question 1**

Summaries the process of Electron transport chain ECT and indicate the number of ATP molecules eventually produced:

..............................................................................................................

**Figure 2: Part of the Higher Order Thinking Tool (HOTT)**

***Instrument***

*Transfer test*

In order to assess the effect of the higher order thinking scaffolding tool, the students were given a transfer test. The transfer test was given to the whole class on the day that the class attendance was expected to be high. Questions were at higher thinking standard to ensure the validity of the tool. The test composed of five multiple choice questions that required Critical Thinking (CT) and most of these questions were adopted from: http://www.namrata.co/category/metabolism-carbohydrates/multiple-choice-questions-metabolism-carbohydrates/.The questions were all designed according to Bloom's Taxonomy description of higher order thinking where students needed to analyse, evaluate and create their knowledge to answer the question correctly.

*Post-test and retention test*

Students wrote the retention test three weeks after they attended the lessons. The test was exactly the same as the post-test and some students could tell that it was a repetition, and this was done purposively to test the degree of students' knowledge retention. Students were not informed about the date of the test though the researchers briefed them about this test on the first day of the class. The test composed of nine multiple choice questions and one short answer question. The questions were designed in a way that measured students' understanding of the learned concepts.

*Ethical considerations*

A written consent from the Marseille University (host university) was granted, assuring and explaining the nature of the study to be conducted as free of destructive ethical issues in any way. Assurance was made to all the participants that under no circumstance will one be disadvantaged by this research. The researchers explained the nature of the study to the whole group of participants. A promise was made that the outcome (the test scores and all the responses) obtained from this research will be treated with great confidentiality and no marks will be used for any other purpose other than this study.

## Results

***Post-test scores***

ANOVA test showed no significant difference in the post-test means among the four treatments, with df = 3, $F$= 1.31 and $p$= 0.28. However, the mean for the HOTT group (M=7.25) was slightly higher than the other three groups: AOT M= 6.84, AOT/HOTT combination M= 6.12 and the control group M= 6.13. The Different tools used seemed to have no effect on short term knowledge retention.

***Transfer test scores***

Student' overall performance was good in the transfer test. One of the goals for this study was to improve students' ability to transfer what they learned from class to solve similar problems in the same context. Higher thinking order scaffolding tool (the question card) in a flipped classroom was used in search for the answer to the study questions. Moreover, the flipped classroom was used to give students time to watch videos at their own comfort. In general students did well in the transfer test. The results showed no significant difference between the four means. The means of Control group ($M$=4.27), AOT group ($M$=4.78), HOTT group ($M$=4.89) and AOT/HOTT ($M$=3.53) showed a weak variation (see Table 1). The test score at $df$=3, $F$= 1.11 gives the value of $p$ = 0.35 which means there is no significant difference between means for transfer test among the four treatments.

**Table 1: Means and standard deviation of retention and transfer test in all the four conditions**

| | Conditions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HOTT | | SA | | Combine | | Control | |
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Transfer test (max = 10 ) | 4,89 | 2,32 | 4,78 | 2,39 | 3,53 | 1,94 | 4,27 | 3,11 |
| Retention test (max = 13 ) | 6,88 | 1,96 | 7,19 | 2,59 | 6,13 | 1,36 | 4,94 | 2,3 |

***Test score for retention test***

The retention test for the four treatments were again tested and found to be significantly different from each other using one-way ANOVA. There was a significant difference between the means as it was tested at $p$=0.05 level. The test score (df=3, F=3.73 and $p$= 0.02) showing the variation between the means (see Table 1). The data were further analysed to see exactly which means were significantly different from others, a multiple comparison test was run. A Tukey HSD post hoc test was used to compare these means as shown in Table 2. When the means were compared, it was found that there was a significant difference between the retention mean for the AOT group (M= 7.19) and the control group (M= 4.94) which gave a $p$ = 0.02. This suggests that as far as retention is concerned, AOT scaffolding tools had a positive effect on retention in comparison to the control group that had no scaffolding tools. On the other hand, the AOT and HOTT groups were not different concerning the retention test ($p$= 0.98) and HOTT group archived a better score to the retention test than the control group ($p$ = 0.05). This information may suggest that both HOTT and AOT can improve retention though the impact is slightly different with AOT scaffolding appeared to be the best with the highest mean (M= 7.19). Concerning the Combined tools group, it might be assumed that the performance might reduce due to what can be termed as cognitive overloads. Even though the results showed no significant difference between the mean for AOT (M=

7.19), HOTT (M= 6.88) and the HOTT/AOT combination (M= 6.13) as far as retention is concerned, the mean for the combination was the lowest, so the assumption can be true. On the separate study Zydney (2010) used combination of two scaffolding tools (higher order thinking tool and organising tools) to measure students' misconceptions, multiple prospective and problem understanding in a complex environment. The author assumed that the combination of these two tools would be more effective at reducing misconception, improving understanding and students' multiple prospective.

If we analyse the performance on a particular question, question one required students to know the proper sequence involved in Electron Transport Chain ETC. Most students got this correct, with Group one (AOT group) the highest 75% and the Combination group (AOT/HOTT) the least with only 61 percent of the students who got this question correct and they were 2 percent lower than the control group 63%. This gives the impression that, students managed to grasp the core of the lesson which was more on the two final steps or stages of glucose metabolism under aerobic respiration namely Electron transport chain and oxidative Phosphorylation. This way of scaffolding helped students to organize and make a schema out of the information provided via the video and in the class. They could also use the past experience since they already covered the first two steps, glycolysis and the Krebs cycle before they attended this lesson.

**Table 2: Multiple comparizons of the means based on retention test**

| (I) Condition | (J) Condition | Mean Difference (I-J) | STD. Error | *p*-value |
|---|---|---|---|---|
| AOT | HOTT | 0.31 | 0.75 | 0.98 |
| | AOT/HOTT | 1.06 | 0.75 | 0.49 |
| | Control | 2.25 | 0.73 | 0.02* |
| HOTT | AOT/HOTT | 0.75 | 0.75 | 0.74 |
| | Control | 1.93 | 0.73 | 0.05* |
| AOT/HOTT | Control | 1.18 | 0.73 | 0.38 |

Significant results *

**Discussion**

The objective for the current study was to examine the impact of scaffolding tools as attached to the flipped Classroom Model of teaching on university students' retention and knowledge transfer. The research made hypotheses: 1) AOT would better improve knowledge retention, 2) HOTT would best improve knowledge transfer, 3) The combination of the two tools (AOT and HOTT) impact a little bit both retention and transfer. The two tools were given in accordance with the theory of Zone of Proximal Development, to provide support at the point where the child would be independently carrying out difficult tasks on his or her own. Bruner and Ross (1976) defined scaffolding as a process in which a child or novice could be assisted to achieve a task that they may not be able to achieve unassisted. It has also been linked to Levy Vygotsky who believed that learning occurs at the social or inter-individual level and emphasized the role of social interactions as crucial to cognitive development. Devereux (2014) further emphasized that, the zone of proximal development level can be taken as the shared space between tutors, students and lecturers in which collaboration is taking place to tackle tasks through discussion and mystifying tasks together to build students' learning capacity eventually to undertake tasks of the same level unaided which is the focal point of Scaffolding theory.

About the retention, the AOT and HOTT involved better scores compared to the control groups, so both have positive impact on the students' retention. However, the AOT group did not outperform significantly compared to HOTT group. The AOT used two types of Analogies, textual analogies and pictorial analogies. Bean et al. (1990) compared the effects of unexplained textual analogies to the group that had no analogies, on enzyme catalyst and they found no difference between the two groups. Simons (1984) as explained in Bodner and Orgill (2004), used textual analogy on electricity to two groups of high school students in his study, experimental group was compared to the control group. He found that the experimental group outperformed the control group. The current study can be used to supplement their studies; in this study the researchers explained all the analogies to students before the lesson and this might be a contributing factor to the effectiveness of the tools. Henceforth, the researchers made a strong conclusion that, the effectiveness of Analogies depends on how well the students understand and how well the analogies were explained.

About transfer**,** the second hypothesis suggests that HOTT could help students become independent thinkers to enable them to transfer knowledge from the lesson to the similar problems in different concepts. Results from the current study did not give a statistical variation in the transfer score means. However, students from the HOTT group scored slightly better (M= 4.89) than the colleagues from the three other groups. The researchers assume that the Flipped classroom model also contributes to the learning because the control group performance was not far from the score from the group using scaffolds and it was not a bad result, hence the study tends to be in line with the study by Ng (2014) who emphasised that "during inverted classroom model, students would focus on and engage in activities that foster deeper understanding a higher-order thinking through discussions, practical work and problem solving tasks that they do individually or collaboratively in small groups"(p.18).

About the impact of multiple tools**,** in case of the AOT/HOTT group, the results showed that the combination of the two scaffolding tools reduced the students' ability to transfer and this might be the results of overloading, thus the AOT/HOTT group scores were always under the AOT group and HOTT group's scores (for post, retention and transfer tests), even if they were not significant. When students are dealing with novel information, they need to create a schema to enable assimilation; it will be difficult to process information to the working memory when multiple instructions are involved (Moreno, 2004; Tuovinen, 2000; Moreno & Valdez, 2005; Mayer & Moreno, 2003). Moreno (2004), further stated that working memory load may be affected either by the intrinsic nature of the learning (intrinsic cognitive load) or by the manner in which the tasks are presented. This means the transfer of new information from working memory to long term memory can be hindered by the way the information is given. This is found to be in line with the findings from Zyden (2010), the study assumed that combining two scaffolding tools may be more effective than a single scaffolding tool, but these results showed that the combination of the two scaffolding tools reduced the performance.

**Conclusion**

Results from the current study did not give a statistical variation in the transfer score means. However, students from the HOTT group scored slightly better (M=4.89) than those from the three other groups. This may be due to the design of the study. The design faced several challenges that may have resulted in lower efficiency of the tools. For example, the time frame allocated for the study was too short, that also did not allow the researchers to conduct a pilot study before conducting this study. Another challenge that may be caused by the time allocated is the critical thinking ability. The research confidently made an assumption that; it requires a long period of time for critical thinking ability to develop (Miri et al., 2007). Therefore, due to the nature and the design of the current study, HOT tools could not be executed ideally. The primary idea for this study was to test the effectiveness of the scaffolding tools embedded in the Flipped classroom model at enhancing natural science education. The current study was on a small group scale therefore the findings are specific to the target group and could not draw a general conclusion for all branches of natural science (Physics, Chemistry and Biology). This study makes an endorsement of the finding from the study by Zyden (2010). The study assumed that combining scaffolding tools could even foster knowledge comprehension more than the single scaffolding tool. Unfortunately, the results came out otherwise, and the students' cognitive process was lower in combined tools. The current study also obtained the same result; the researchers are therefore recommending a further study on what really limits the performance in such environment. In general, there was no literature found in the same area in African countries, hence there is a need for more studies on flipping and scaffolding tools in around African countries only then a concrete conclusion will be made on the use of scaffolding tools. The presented research focused on the students' knowledge transfer and retention at the University of Namibia and in particular related to the effects of two scaffolding tools (Advanced Organization Tool and Higher-order thinking tool) in a flipped classroom course on Biochemistry. We started from the consideration that scaffolding tools could be used to improve university science students' transfer level and knowledge retention. The tools were chosen based on research in the educational literature. The technology used in this research (video, e-portfolio, Google drive) was selected with the aim to be flexible and to support the collaboration between the students.

In conclusion, the study showed that the scaffolding tools were particularly effective concerning retention. No significant differences between groups have been found on the students' transfer scores. Moreover, even if there is no clear significant difference, the use of multiple tools in the same groups seemed to impact negatively students' performances. In general, a scaffold reflection is necessary in a good design and application of flipped method. This study might help to design interesting use of the flipped classroom for science teachers in Africa, improving students' academic success. Indeed a good design in the active pedagogy can really motivate and engage more students, developing their critical and problem solving competences. This study also shows how the flipped classroom model is a flexible and adaptable pedagogical method that can be supported by other different pedagogical models, with the introduction of the technology. For this reason, we consider that these pedagogies can be easily adopted in the African countries, with or without the support of the basic or advanced technology.

Finally, the context of analysis was limited in only one context and we plan to improve this study with a more extended sample in some African countries, with an open collaborative and international design research on flipped method. More space will be given to the use of the class portfolio and supporting technology.

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