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The role of directed activities related to texts in enhancing traditional laboratory experiments for qualitative salt analysis learning

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ABSTRACT

Qualitative salt analysis is widely recognized as a challenging topic in chemistry due to its abstract concepts and the large amount of complex information involved. This often places high cognitive demands, limiting students' ability to integrate experimental observations with conceptual knowledge during laboratory-based activities. This study investigated the effects of integrating directed activities related to texts (DARTs) into traditional laboratory experiments on students' achievement, knowledge retention, cognitive load, and learning efficiency in qualitative salt analysis. A quasi-experimental design was employed involving 100 Form 4 science stream students from two fully residential secondary schools, who were equally assigned to either a traditional laboratory experimental group (control) or a DARTs-integrated experimental group (treatment). Data from pre-test, post-test, and delayed post-test were analyzed quantitatively. Results showed that the treatment group demonstrated significantly higher achievement and retention, lower perceived cognitive load, and higher learning efficiency than the control group, indicating that structured DARTs activities facilitate deeper cognitive processing and a more efficient use of cognitive resources during laboratory learning. The study provides empirical evidence supporting the potential value of integrating DARTs into laboratory-based instruction to enhance conceptual learning in qualitative salt analysis, compared with traditional laboratory methods.

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1. INTRODUCTION

In learning chemistry, students are required to connect new concepts to their prior knowledge, thereby building a solid foundation in core principles [1]. This cognitive emphasis is reflected in chemistry curricula worldwide, such as the Cambridge International General Certificate of Secondary Education (IGCSE) [2], the Singapore Science (Chemistry) syllabus [3], and Malaysia's National Curriculum Standards [4]. Based on these curricula, students are expected to actively engage in learning through critical thinking and hypothesis testing in both theoretical lessons and practical laboratory work, including qualitative salt analysis. However, relatively low performance in the science domain of the Programme for International Student Assessment (PISA) 2022, with a mean score of 418 and only 52% reaching minimum proficiency [5], [6], suggests that many Malaysian students entering Form 4 Chemistry are likely to experience difficulties in understanding new chemical concepts due to limited foundational scientific literacy.

Such limitations may constrain the integration of prior knowledge with new information, thereby increasing demands on working memory and potentially affecting academic achievement [7].

These learning constraints are further amplified in specific chemistry topics such as qualitative salt analysis. Qualitative salt analysis has consistently been identified as one of the most difficult topics to understand, including among Malaysian students, as evidenced in local research [8]–[10]. The abstract nature of its chemical concepts and the large amount of complex information involved throughout the learning process [8]–[10] make it challenging for students to connect hands-on laboratory activities with conceptual understanding meaningfully [11], [12]. As a result, students tend to focus more on the procedural aspects of experiments and on obtaining "correct" results while neglecting the important underlying principles [13], thereby limiting active cognitive engagement (e.g., integrating experimental evidence with chemical principles) and hindering the development of deep conceptual understanding [14], [15].

This persistent challenge underscores the urgent need for instructional strategies that promote active cognitive processing while effectively managing cognitive load in laboratory-based experiments. In this regard, approaches that integrate textual scaffolding with hands-on activities, such as directed activities related to texts (DARTs), may offer a promising means to enhance students' conceptual understanding of qualitative salt analysis. Accordingly, this study is designed based on constructivist and cognitive load theory, integrating DARTs into laboratory-based experiments to support active knowledge construction and manage students' cognitive load.

The implementation of DARTs typically involves learners working collaboratively in pairs or groups using a variety of text-based activities, such as reconstruction (i.e., underlining or highlighting, labelling, segmenting, diagrammatic representation, tabular representation and questioning) and analysis (i.e., text completion, diagram completion, table completion, sequencing and prediction) [16], [17]. The DARTs method has improved a variety of learning outcomes, including students' writing skills [16], reading comprehension [18]–[20], critical thinking [21], engagement with science-related texts [22], and enhancing biology and chemistry learning [15], [23]–[25]. These DARTs activities foster active meaning-making on existing cognitive foundations as students progressively complete [26], and align with constructivist learning theory, which emphasizes that learners actively construct knowledge by integrating new information into existing mental frameworks or schemas through active engagement and social interaction.

As there is limited research on DARTs' method for addressing challenges in learning qualitative salt analysis [10], [15], Shamsulbahri and Zulkiply [15] provide a useful foundation for the effectiveness of DARTs in this context. In their research, the group that received the combined method (DARTs integrated into theoretical lessons together with traditional practical lessons) achieved the highest mean scores, followed by the DARTs group (which received only DARTs integrated into theoretical lessons) and, lastly, the experimental group (which received only traditional practical lessons). Further analysis comparing these two conditions (DARTs integrated into theoretical lessons vs traditional practical lessons) revealed that the DARTs method significantly improved students' understanding by addressing cognitive load issues commonly encountered when learning qualitative salt analysis through traditional practical lessons.

Drawing from this research, the present study identifies several gaps that offer valuable opportunities for further investigation. First, the DARTs method was applied only in theoretical lessons, and the effect of integrating DARTs into laboratory-based chemistry experiments remains unexplored. Second, students' achievement in qualitative salt analysis was measured solely in terms of short-term retention, assessed immediately after the study phase, leaving its effects on long-term memory yet to be investigated. Third, the explanation of how DARTs reduces cognitive overload in classroom-based theoretical lessons relies solely on post-test scores, without incorporating specific measures of cognitive load. Finally, although achievement and cognitive load significantly influence learning efficiency [27], neither this research nor previous studies have specifically examined the learning efficiency of the DARTs method within the context of qualitative salt analysis experiments in chemistry.

Therefore, this study was conducted to address existing challenges in learning qualitative salt analysis and the key research gaps identified in prior DARTs-based studies, particularly the limited application of DARTs in laboratory-based settings and the lack of investigation into knowledge retention, cognitive load, and learning efficiency. The present study aims to examine the extent to which integrating DARTs into traditional laboratory experimental method (DARTs-iExp) enhances students' achievement, knowledge retention, cognitive load, and learning efficiency in qualitative salt analysis, compared to the traditional laboratory experimental method (TdExp) alone. These research questions (RQ) guided the study:

- Is there any significant difference in students' achievement in the learning of qualitative salt analysis in chemistry when using different types of laboratory-based experimental methods (TdExp vs DARTs-iExp)?
- Is there any significant difference in students' knowledge retention in the learning of qualitative salt analysis in chemistry when using different types of laboratory-based experimental methods (TdExp vs DARTs-iExp)?

- Is there any significant difference in students' cognitive load in the learning of qualitative salt analysis in chemistry when using different types of laboratory-based experimental methods (TdExp vs DARTs-iExp)?
- Is there any significant difference in the learning efficiency of different types of laboratory-based experimental methods (TdExp vs DARTs-iExp) in the context of learning qualitative salt analysis in chemistry?

2. METHOD

2.1. Participants and design

Purposive sampling was employed to select 100 Form 4 science stream students, with a mean age of 16 years, from two fully residential schools (School A and School B), with 50 students from each school. This selection was intended to enhance internal validity. The students from School A were assigned to the experimental condition, while the students from School B were assigned to the control condition. The sample size exceeded commonly recommended minimum group sizes for experimental research in education [28]. In addition, drawing on general statistical power considerations reported in the literature, this sample size is considered adequate for detecting medium-to-large effects in group-comparison studies [29]. The use of fully residential schools also allowed researchers to control for extraneous variables, such as internet access and other external resources, which could have influenced students' achievement, knowledge retention, cognitive load, and the learning efficiency of the instructional methods used during the study.

Prior to the study, all participants completed a pre-screening test to confirm their limited prior knowledge of the salt topic. This was further verified by school teachers through a review of lesson plans, ensuring that the participants had not studied the topic before the study commenced. Additionally, a Welch t-test was performed on the pre-test results to verify group equivalence at the outset.

This study adopted a quasi-experimental design. The independent variable was the type of laboratory-based experimental method, with two conditions: the TdExp and the integration of DARTs-iExp. The dependent variables were students' achievement, knowledge retention, cognitive load, and learning efficiency, as analyzed quantitatively. The experiment consisted of seven compulsory practical sessions on qualitative salt analysis, during which students conducted laboratory-based experiments.

2.2. Materials

The materials used in the present study were as: i) experimental procedures and discussion handout (qualitative analysis of salt); ii) DARTs experimental sheet handout (qualitative analysis of salt); iii) Qualitative Analysis of Salt Test (QAST); iv) Delayed Qualitative Analysis of Salt Test (D-QAST); and v) NASA Task Load Index (NASA-TLX) questionnaire. These materials were prepared specifically in alignment with the five learning standards outlined in the Malaysian Chemistry Curriculum specification for Secondary Four. The learning standards are as: i) Test the solubility of salt in water and classify them into soluble and insoluble salts through experiment (6.9.1); ii) Construct an ionic equation using the continuous variation method (6.9.4); iii) Investigate the effect of heat on salts through experiment (6.10.2); iv) Identify the cations and anions present in salt through experiment (6.11.1); and v) Describe the confirmatory test to identify cations and anions (6.11.2). Note that the numbering of the five learning standards corresponds to their respective experiments in the Form 4 Chemistry Textbook within the Malaysian Secondary School Chemistry Curriculum. Learning standard 6.10.2 involves two experiments, whereas learning standards 6.9.1, 6.9.4, 6.11.1, and 6.11.2 each involve one experiment. All materials were prepared in English. Descriptions of each material used in the present experiment are provided in subsection.

2.2.1. Experimental procedures and discussion handout (Qualitative analysis of salt)

The handout on experimental procedures and the discussion regarding the qualitative salt analysis were taken from the Form 4 Chemistry Textbook (of the Malaysian Secondary School Chemistry Curriculum), which is the primary reference used by all Malaysian teachers and students to learn chemistry during practical work in the laboratory. Seven sets of compulsory experiments in the qualitative salt analysis (i.e., Unit 6 in the textbook) are included in this handout, with the following experimental aims, which correspond to the textbook outline:

- Experiment 6.5: To investigate the solubility of various salts in water
- Experiment 6.6: To construct an ionic equation for the formation of lead(II) oxide
- Experiment 6.7: To investigate the action of heat on carbonate salts
- Experiment 6.8: To investigate the action of heat on nitrate salts
- Experiment 6.9: To identify the anions present in aqueous salt solution
- Experiment 6.10: To identify the cations present in aqueous salt solution
- Experiment 6.11: To confirm the presence of cations in aqueous solution

Each experiment in these handouts includes details on the experiment's aim, problem statement, hypothesis, variables, materials, apparatus, procedures for conducting the experiment, results, interpretation of observations and data, and discussion questions.

2.2.2. DARTs experimental sheet handout (Qualitative analysis of salt)

The researcher developed the DARTs experimental sheet handout to align with the lesson's five learning standards. Adapted from the experimental procedures and discussion handout, it retains key sections (e.g., the aim of the experiment and the problem statement) for the seven compulsory experiments in the qualitative salt analysis. The researchers integrated DART-based reconstruction and analysis activities into specific sections of each experiment, as detailed in Tables 1-7. The content of the handout was validated for internal validity by six expert panels in chemistry education. These experts, all experienced chemistry teachers with over ten years in the field, hold qualifications in chemistry education and have served as examiners for the Malaysian Certificate of Education in Chemistry. The panel members strongly agreed that the material is suitable for the target population, easy to understand, effective during learning sessions, and aligned with learning objectives.

Additionally, they generally found the allocated implementation time to be adequate. Regarding content validity, each experiment (seven in total) was rated on a 4-point relevance scale. All item-CVI (I-CVI) values were 1.00, resulting in an overall scale-CVI average (S-CVI/Ave) of 1.00, indicating high relevance. The face validity index (FVI) for clarity was 0.90, suggesting that the handout is highly comprehensible.

Table 1. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.5

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Hypothesis	Text completion (fill in the blanks with a sentence)	Complete the hypothesis for the experiment.	Reconstruction
Variables		Complete the responding variable in the experiment.	
Apparatus	Highlighting (by ticking)	Choose a suitable apparatus for conducting the experiment.	Analysis
Procedures	Drawing + labelling	Draw and label the diagrams based on the given procedures.	Reconstruction + Analysis
Results	Table completion (fill in the blanks with a single word)	Complete the incomplete table based on the observations.	Reconstruction
Interpreting Data	Drawing/table construction	Draw an appropriate diagram or table to classify the solubility of different types of salts.	Reconstruction / Analysis

Table 2. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.6

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Variables	Text completion (fill in the blanks with a sentence)	Complete the manipulated and responding variables of the experiment.	Reconstruction
Materials	Text completion (fill in the blanks with a phrase)	Complete the list of materials for the experiment.	
Apparatus	Text completion (fill in the blanks with a single word)	Complete the list of apparatus for the experiment.	
Procedures		Complete the procedures of the experiment.	

Table 3. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.7

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Hypothesis	Text completion (fill in the blanks with a sentence)	Complete the hypothesis for the experiment.	Reconstruction
Materials	Highlighting (by ticking)	Choose suitable materials for conducting the experiment.	Analysis
Procedures	Sequencing	Arrange the disordered text into the correct procedure for conducting the experiment.	Reconstruction
Results	Table construction	Construct an organized table of observations.	Analysis
Discussion	Text completion (fill in the blanks with a single word)	Complete the chemical equation and the color of reactants and products.	Reconstruction

Table 4. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.8

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Hypothesis	Text completion (fill in the blanks with a sentence)	Complete the hypothesis for the experiment.	Reconstruction
Variables	Text completion (fill in the blanks with a sentence)	Identify and fill in the manipulated and responding variables of the experiment	
Materials	Text completion (fill in the blanks with a single word or phrase)	Complete the list of materials for the experiment.	
Apparatus	Text completion (fill in the blanks with a phrase)	Complete the list of apparatus for the experiment.	
Procedures	Text completion (fill in the blanks with a single word or phrase)	Complete the procedures of the experiment.	
Result	Table construction	Construct an organized table of observations.	Analysis
Discussion	Text completion (fill in the blanks with a single word)	Complete the chemical equation and the color of the products.	Reconstruction

Table 5. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.9

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Materials	Text completion (fill in the blanks with a single word or phrase)	Complete the IUPAC name of the solutions and their chemical formulae.	Reconstruction
Procedures	Prediction (by matching the procedures)	Match the tests for anions to the set of procedures, and justify your answers.	
Result	Table completion (fill in the blanks with phrases)	Complete the incomplete table based on the observations made during the experiment.	
Discussion	Text completion (fill in the blanks with a word, phrases, sentences) + drawing + labelling	Write a complete list of materials and apparatus, procedures and observations. Then, draw and label diagrams based on the completed procedures.	Reconstruction + Analysis

Table 6. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.10

Section integrated with DARTs	DARTs activity	Task	Type of DARTs activity
Hypothesis	Text completion (fill in the blanks with sentences)	Complete the hypothesis for the experiment.	Reconstruction
Variables		Complete the responding variable of the experiment.	
Materials	Text completion (fill in the blanks with a single word or phrase)	Complete the list of materials for the experiment.	
Apparatus		Complete the list of apparatus for the experiment.	
Procedures	Sequencing	Arrange the disordered text procedure in conducting the experiment based on an orderly diagram.	
Interpreting data	Table completion (fill in the blanks with a single-word sentence)	Complete the incomplete table based on the observations made during the experiment.	
Discussion	Underlining + text completion (fill in the blanks with phrases or sentences) + drawing + labelling	Underline the important information regarding the procedures for identifying cations using NaOH solution. Write a complete list of materials, apparatus, procedures and observations. Then, draw and label diagrams.	Analysis + Reconstruction

Table 7. DARTs experimental sheet handout (qualitative analysis of salt) for Experiment 6.11

Section integrated with DARTs	DARTs activity	Task	Type of DARTs Activity
Hypothesis	Text completion (fill in the blanks with a sentence)	Complete the hypothesis for the experiment.	Reconstruction
Variables		Complete the manipulated and controlled variables of the experiment.	
Apparatus	Text completion (fill in the blanks with a single word or phrase)	Complete the list of apparatus in the experiment.	Reconstruction
Procedures	Text completion (fill in the blanks with a single word, phrases, or sentences)	Complete the procedures of the experiment.	
Results/ Observation		Complete the text based on the observations made during the experiment.	

2.2.3. Qualitative Analysis of Salt Test

The QAST was employed as a pre-screening instrument in the pre-study phase and as an assessment tool to evaluate students' achievement in qualitative salt analysis during the test phase. The instrument comprised three sections: section A (10 objective questions, 1 mark each), section B (1 structured question, 10 marks), and section C (1 essay question, 10 marks), with a total possible score of 30 marks. To ensure content validity, the QAST was reviewed by the same six expert panel members who validated the DARTs Experimental Sheet handout. They unanimously confirmed that the test items were appropriate for the target population, clearly worded, answerable within the given time and aligned with the learning standards. Each of the 18 test items was rated on a 4-point relevance scale, yielding I-CVI values of 1.00 across all items. This resulted in an overall S-CVI/Ave of 1.00, indicating strong content validity. For reliability, Fleiss's Kappa was 0.86, indicating almost perfect agreement among evaluators. Additionally, the test demonstrated good internal consistency (Cronbach's alpha=0.73). Item analysis revealed a difficulty index of 0.49, indicating moderate difficulty, and a discrimination index of 0.47, confirming that the test effectively differentiates between students of varying proficiency.

2.2.4. Delayed Qualitative Analysis of Salt Test

The D-QAST was used to evaluate students' knowledge retention. It was adapted from the QAST, maintaining the same number of questions across all sections. To avoid participants' familiarity with the content, modifications were made across all sections. In section A, the positions of the questions and the order of the answer choices were shuffled. In sections B and C, the letters representing substances and the positions of the diagrams were also changed. All six expert panel members agreed that the content of the D-QAST remained comparable to the QAST.

2.2.5. NASA-TLX questionnaire

The NASA-TLX questionnaire [30] is a subjective instrument commonly used to measure perceived cognitive load [31], [32] across diverse areas [33], including education, and has demonstrated good reliability, with a Cronbach's alpha coefficient of 0.73 [34]. The questionnaire consists of two sections: sections A and B. In section A, participants rated their perceived workload on each of six subscales, ranging from 0 (very low) to 100 (very high). The six workload subscales are mental demand (MD), physical demand (PD), temporal demand (TD), performance (PE), effort (EF), and frustration (FR). In section B, participants identified the most significant contributors to their workload by selecting between the following paired items: PD/MD, TD/MD, OP/MD, FR/MD, EF/MD, TD/PD, OP/PD, FR/PD, EF/PD, TD/OP, TD/FR, TD/EF, OP/FR, OP/EF, and EF/FR.

2.3. Procedures

Ethical approval was obtained from the university's Human Research Ethics Committee (Non-Medical). Permission was subsequently obtained from the Ministry of Education, the Sarawak State Education Department, and the principals of the two selected local, fully residential secondary schools (referred to as School A and School B). Parental consent was also obtained prior to students' participation.

A purposive sampling strategy was employed to ensure that only students with low prior knowledge of qualitative salt analysis were included. All potential participants first completed a 50-minute pre-screening test, the QAST, and those who scored 10 marks or below out of 30 were selected. A total of 100 qualified participants were assigned to two intact groups: the treatment group (School A) and the control group (School B), with 50 participants per group, in line with the quasi-experimental design of the study.

Initially, the researcher engaged in team teaching with the students' current chemistry teacher three weeks prior to the start of the salt subtopic. This was done to familiarize students with the researcher's presence and minimize potential changes in behavior during the qualitative salt analysis lessons, which were conducted solely by the researcher. To familiarize students with the instrument, the researcher administered the NASA-TLX twice during the acids and bases learning sessions, immediately before the salt subtopic.

During the study phase, participants were instructed by the researcher to work in pairs to learn the seven compulsory experiments in qualitative salt analysis in a practical laboratory setting. The treatment group used the DARTs experimental sheet handout, while the control group used the conventional Experimental Procedures and Discussion handout. Both groups followed their respective school timetables to complete 21 sessions, each lasting 30 minutes.

At the end of the study phase, the NASA-TLX questionnaire was administered to all participants, taking up to 10 minutes to complete. Following this, participants completed the same QAST that they answered during the pre-screening test sessions. After a three-week interval, all participants completed the D-QAST. The duration to complete both the QAST (post-test) and the D-QAST (delayed post-test) was 50 minutes each. Participants were debriefed about the experimental manipulation they had been involved in at the end of the test phase.

3. RESULTS

The data were analyzed using independent samples t-tests to compare the two groups in terms of participants' achievement (RQ1) and learning efficiency (RQ4). Welch's t-test was used to analyze participants' prior knowledge (pre-screening test), knowledge retention (RQ2) and cognitive load (RQ3) due to a violation of the assumption of homogeneity of variance.

3.1. Pre-screening test

The average score of the control group (TdExp: M=3.62, SD=1.09) and the treatment group (DARTs-iExp: M=3.48, SD=1.43) did not differ significantly ($t(91.35)=0.55$, $p=.583$). This indicates that both groups had comparable prior knowledge of the salt topic before the study. As both mean scores were well below 10 out of 30 marks, this further reflects a limited understanding of the topic, which had not yet been introduced to the participants.

3.2. Research question 1

An independent-samples t-test revealed a significant difference in students' achievement in qualitative analysis between the two experimental methods: TdExp (M=7.60, SD=3.52) and DARTs-iExp (M=12.08, SD=4.76); $t(98)=-5.35$, $p<.001$. Cohen's d was calculated as the mean difference between the control and treatment groups, yielding $d=-1.07$, indicating a large effect size. This suggests that students in the DARTs-iExp group achieved significantly higher scores in qualitative analysis than those in the TdExp group.

3.3 Research question 2

The independent-samples Welch's t-test revealed a statistically significant difference in students' knowledge retention between the groups: TdExp (M=3.76, SD=1.79) and DARTs-iExp (M=11.98, SD=4.17); $t(66.50)=-12.82$, $p<.001$. The effect size (Cohen's $d=-2.56$) indicates an exceptionally large effect. This result suggests that students who engaged in the integration of DARTs into the traditional laboratory experimental method exhibited significantly higher knowledge retention than those taught using the traditional laboratory experimental method.

3.4 Research question 3

The independent-samples Welch's t-test revealed a statistically significant difference in students' perceived cognitive load between the experimental methods: TdExp (M=58.43, SD=10.28) and DARTs-iExp (M=48.61, SD=13.17); $t(92.56)=4.16$, $p<.001$. The effect size (Cohen's $d=0.83$) indicates a large difference. This suggests that students in the DARTs-iExp group experienced significantly lower perceived cognitive load compared to those in the TdExp group.

3.5 Research question 4

An independent samples t-test revealed a statistically significant difference in learning efficiency between the two groups: TdExp (M=-0.61, SD=0.87) and DARTs-iExp (M=0.61, SD=0.81); $t(98)=-7.22$, $p<.001$. The effect size (Cohen's $d=-1.44$) indicates a very large effect, suggesting that integrating DARTs into the traditional laboratory experimental method had a substantial positive impact on students' learning efficiency. The learning efficiency index (E) was 0.61 for the DARTs-iExp group and –0.61 for the TdExp group, indicating that students in the DARTs-iExp group learned more efficiently than those in the TdExp group. In contrast, those in the TdExp group demonstrated lower efficiency.

4. DISCUSSION

The results of the present study indicate that the DARTs method contributed to higher achievement in learning qualitative salt analysis, consistent with the foundational work of Shamsulbahri and Zulkiply [15]. Activities embedded within the DARTs experimental sheet handout required students to actively interpret information and establish connections across different sections of the text [35]. In text and table completion tasks, learners derived meaning through contextual cues and cross-referenced relevant sections of the experiment, such as the apparatus description, to inform procedural responses. Similarly, synthesis across sections was evident during the completion of results and discussion components (Experiments 6.7–6.11), irrespective of sequence.

Sequencing tasks (Experiments 6.7 and 6.10) may have further supported this process by requiring students to reorganize procedural steps using visual representations, reinforcing the linkage between procedural knowledge and conceptual understanding. In cognitively demanding prediction tasks (Experiment 6.9), students drew upon prior knowledge of salt solubility and reagent interactions developed in earlier experiments (Experiment 6.5) to justify responses. These patterns of engagement with the DARTs experimental sheet align with constructivist principles, which emphasize the integration of prior knowledge with new learning experiences [36], [37]. In the context of these laboratory-based experiments, such activities required students to engage cognitively through interpretation, application, and justification in conjunction with hands-on practical work, which may reflect deeper cognitive processing [38].

In contrast, the control group was provided with an experimental procedures and discussion handout, a traditional approach in which procedural steps, data, and explanations were fully pre-structured. Under these conditions, opportunities for integrative processing were limited, with learning likely emphasizing procedural execution over meaning-making. This may have constrained conceptual development [14], [15] and contributed to lower achievement outcomes.

Nevertheless, the traditional format provided a structured framework common to both groups, upon which the DARTs intervention was integrated. Across conditions, experimental objectives, procedures, and content remained comparable. The key distinction lay in learner engagement: the control group received complete information, whereas the DARTs group actively analyzed and reconstructed information throughout the process. As students in both groups had prior exposure to traditional laboratory practices, familiarity with standard procedures likely provided a shared cognitive framework that supported engagement with the DARTs activities. Accordingly, while the DARTs approach was associated with higher achievement, the role of traditional instruction as a foundational context should be acknowledged.

Positive effects of DARTs on achievement have been reported across disciplines, particularly in language learning [16], [18]–[20] and selected STEM domains [21]–[25]. However, its application in laboratory-based experimental settings remains limited. This restricts the generalizability of prior conclusions, as such contexts do not capture the role of DARTs in experimental work. This study, therefore, extends the existing evidence base by demonstrating the applicability of DARTs in a laboratory-based experimental setting.

Beyond achievement, integrating DARTs into traditional laboratory experiments appears to be associated with improved knowledge retention, potentially through repeated, meaningful engagement with learning materials that may support retention over time [37], [39]. It should be noted, however, that repeated engagement alone may not necessarily strengthen retention, particularly when excessive repetition overwhelms learners and shifts learning toward rote memorization. In the present study, DARTs activities required active reconstruction and interpretation of information, suggesting a more meaningful form of repeated engagement. This is reflected in the text and table completion activities in the DARTs experimental sheet handout, where students reconstructed missing information, revisited core concepts across contexts, and verified their understanding using experimental cues. Such iterative engagement is consistent with deeper cognitive processing, which the literature suggests may support improved memory encoding [39], [40].

Retention gains may also be supported by drawing and labelling tasks, which required students to transform procedural descriptions into annotated diagrams, as observed in Experiments 6.5 and 6.9. These activities encouraged learners to reorganize information into spatial representations while integrating key experimental elements with prior knowledge, thereby potentially promoting elaborative processing [41]. The integration of verbal and visual representations is consistent with Dual Coding Theory and may support stronger memory encoding and retrieval pathways [42], [43].

In contrast, the control group engaged more directly with the provided materials without structured opportunities for reconstruction or representational transformation. This may have limited deeper processing and opportunities for elaboration, potentially contributing to lower retention outcomes [44]. Overall, these findings extend the foundational work of Shamsulbahri and Zulkiply [15], which primarily focused on short-term retention, by suggesting that DARTs may also support more sustained learning in qualitative salt analysis within laboratory-based settings.

In addition to its effects on retention, the DARTs method also appears to be associated with lower perceived cognitive load. It should be noted that cognitive load in this study was operationalized using the NASA-TLX, which measures perceived mental workload through students' self-evaluation [30]. While this serves as an established proxy for cognitive load [31], the instrument does not explicitly distinguish between intrinsic, extraneous, and germane cognitive load components. Therefore, interpretations of specific cognitive load mechanisms are grounded in theoretical inference rather than direct measurement.

The embedded scaffolding within the DARTs experimental sheet handout restructures complex information and directs students' attention to essential elements, thereby potentially supporting schema construction and sustained engagement with key chemical concepts. For instance, in Experiment 6.10, students organized results into structured comparison tables, facilitating clearer pattern recognition and reducing interpretive demands. Similar support is evident in activities such as annotated diagram construction (Experiment 6.5), provision of key components in chemical equations (Experiment 6.7), worked examples for selecting appropriate tests and procedures (Experiment 6.9), and structured procedural representations (Experiment 6.10), which collectively suggest that DARTs may help students manage perceived cognitive load more effectively [45].

Such instructional structuring may reduce unnecessary processing demands, which is conceptually consistent with reductions in extraneous cognitive load and more efficient allocation of working memory resources toward meaningful learning processes [44]. In parallel, strategies such as underlining and highlighting may function as attention-directing mechanisms, potentially supporting schema refinement by helping students focus on relevant information [46]. Unlike the DARTs-supported condition, students in the control group were required to process experimental content more independently, without explicit support to organize and prioritize relevant information. This may have contributed to higher perceived cognitive demands and fewer cognitive resources available for meaningful learning [7], [47].

While Shamsulbahri and Zulkiply [15] suggested that DARTs reduce cognitive overload, their study did not include direct measures of cognitive load. This limits the extent to which cognitive load mechanisms can be empirically confirmed. The present study addresses this limitation by incorporating measures of perceived cognitive load using NASA-TLX, providing evidence of an association between DARTs and lower perceived cognitive demands.

The combined pattern of higher achievement and lower perceived cognitive load observed in the treatment group aligns with the concept of learning efficiency (*E*), which is used to evaluate instructional efficiency through a computational model integrating achievement outcomes and cognitive demands [27]. Learning efficiency (*E*) is operationalized as the standardized mean score for test performance (P) combined with the standardized mean score for test mental effort (R), as expressed in (1). In this study, test performance (P) denotes achievement scores, while test mental effort (R) represents perceived cognitive load scores.

$$\text{Efficiency, } E = Z_{\text{score}}(\text{P}-\text{R}) \,/\, \sqrt{2} \tag{1}$$

A higher *E* value indicates more efficient learning, characterized by higher achievement with lower perceived cognitive load, as observed in the treatment group. Conversely, lower values may indicate comparatively lower learning efficiency, as reflected in the control group. Although previous studies have not explicitly examined the learning efficiency of DARTs in qualitative salt analysis, the observed pattern is consistent with findings from related instructional contexts. For example, Milenković *et al.* [46] reported that multiple representations in chemistry improved achievement while reducing perceived cognitive load. Similarly, Vera *et al.* [48] found comparable outcomes in a flipped classroom setting in biology, while Radulović [49] demonstrated that reduced perceived cognitive load in a game-based response system enhanced both scientific reasoning and learning efficiency in physics education.

These findings address another key gap identified in the foundational research by explicitly examining learning efficiency as a combined outcome of achievement and perceived cognitive load. This provides a more comprehensive evaluation of instructional effectiveness, suggesting that integrating DARTs into the traditional laboratory instruction may enhance both learning performance and cognitive resource efficiency in qualitative salt analysis. Taken together, the evidence from achievement, knowledge retention, perceived cognitive load, and learning efficiency suggests that integrating DARTs into laboratory-based qualitative salt analysis offers a more substantial instructional advantage than traditional laboratory experimental methods. Accordingly, extending the application of DARTs from theoretical classroom settings to hands-on experimental chemistry learning represents the central novelty of this study. To the best of our knowledge, this study is the first to examine DARTs in a laboratory setting while simultaneously evaluating achievement, knowledge retention, perceived cognitive load, and learning efficiency within a single instructional framework. Methodologically, the study further strengthens prior work by incorporating direct measurement of perceived cognitive load using NASA-TLX, enabling a more comprehensive evaluation of instructional effectiveness in laboratory-based chemistry education.

5. CONCLUSION

The findings of this study suggest that integrating DARTs into traditional laboratory chemistry experiments is associated with higher student achievement and retention scores, as well as lower perceived cognitive load. These combined effects indicate that DARTs are a more instructionally efficient approach for learning qualitative salt analysis than traditional laboratory experimental methods. This study contributes to chemistry education by extending the application of DARTs to laboratory-based learning and by providing integrated empirical evidence relating achievement, retention, perceived cognitive load, and learning efficiency within a single instructional framework.

In terms of practical implications, the study demonstrates the value of the instructional materials developed, including the DARTs experimental sheet, the QAST, and the D-QAST, which can be applied in similar educational contexts to structure laboratory learning and assess both achievement and retention. For educators, DARTs provide a structured approach to promote active learning, thereby strengthening cognitive engagement in practical work. Activities such as prediction, text or table completion, and sequencing can be embedded before, during, or after experiments to support conceptual understanding. As these activities require no additional resources or modifications to standard procedures, they are feasible within existing classroom constraints. At the school level, implementation can be supported through professional learning communities, where chemistry teachers share and refine DARTs-based practices, promoting wider adoption across STEM subjects. At the curriculum level, DARTs can be embedded into pre-designed laboratory materials (e.g., laboratory manuals) to enhance the quality of laboratory instruction. In this regard, curriculum developers may provide multiple integration options, enabling teachers to select and adapt activities based on student characteristics and school contexts, thereby facilitating flexible and scalable implementation across diverse settings. One limitation of this study is its focus solely on experimentation within the topic of qualitative salt analysis, which is considered difficult by students. Future research is therefore recommended to explore the integration of DARTs across a wider range of chemistry topics and educational levels, including higher education, to further evaluate the effectiveness and robustness of this instructional approach.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

All participants provided written informed consent before any study-related procedures were initiated, consistent with the protocol approved by the institutional ethics committee.

ETHICAL APPROVAL

This study adhered to the principles of the Helsinki Declaration and all applicable institutional and national legislation. The ethics committee on human research at Universiti Malaysia Sarawak approved the study (approval number: UNIMAS/TNC(PI)/09 – 65/02 (91)).

DATA AVAILABILITY

The authors confirm that the data supporting the findings are available within the article.

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