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Assessment for Learning as a Predictor of Higher-Order Thinking and Problem-Solving in Secondary School Chemistry: A Quasi-Experimental Study

[1]Ovie Adarighofua Faith; [2]Ovie Obarhuarhe Dennis & [3]Diamond Joshua Ogheneochuko

[1,3]Department of Curriculum Education
Delta State College of Education. Mosogar, Nigeria
ovie.faith@descoem.edu.ng/08034675620
Diamond.joshua@descoem.edu.ng/08054029864

[2]Department of Business Education.
Delta State College of Education. Mosogar, Nigeria
ovie.dennis@descoem.edu.ng/08038203431

ABSTRACT
Assessment for Learning (AfL) has been revealed as a practice that can enhance cognitive learning and academic achievement of students. Nevertheless, there is little empirical evidence that studies its causal impact on higher order thinking and problem solving skills in high school chemistry in Nigeria. This paper explored how AfL-based teaching methods impact the cognitive performance of students based on a quasi experimental pre test post-test non-equivalent design. One hundred and eighty two (182) students of four public secondary schools were involved in the study. The instruments that were used to gather data were the Chemistry Higher-Order Thinking Skills Test (CHOTST) and Chemistry Problem-Solving Test (CPST), having reliability coefficients of 0.81 and 0.84, respectively. The Covariance Analysis (ANCOVA) indicated that AfL has a significant effect on higher-order thinking skills, $F(1,179) = 44.86$, $p<.001$, e2=.201, and problem-solving skills, $F(1,179) = 41.02$, $p<.001$, e2=.186. The d effect sizes of 1.05 and 1.02 by Cohen respectively imply very big practical effects. The results indicate that AfL has a strong positive impact on cognitive performance of students in contrast to traditional teaching. The research suggests incorporating the strategies of formative assessment in the curriculum of chemistry and enhancing teacher assessment literacy. The findings give empirical evidence to AfL as an effective intervention to enhance the outcomes of learning science in developing learning conditions.
Keywords: Assessment for Learning; formative assessment; chemistry education; higher-order thinking; problem-solving; Nigeria

INTRODUCTION
Chemistry is a key to scientific and technological progress because it supports such important areas as healthcare, agriculture, energy production, and industrial development. It is a mandatory core science students undertake in senior secondary school in Nigeria and a requirement to be accepted in science-based courses and careers. It is against this strategic significance that students are likely to acquire good analytical skills, conceptual knowledge and problem-solving skills through the study of chemistry. Nevertheless, its importance notwithstanding, the academic performance of students in chemistry has

remained very low, especially in the aspects that demand reasoning, the ability to apply concepts, and the upper levels of cognition (Zudonu and Orji, 2025).

Such consistent poor performance is evident in national examination reports, which show that a significant proportion of Nigerian students focus more on rote memorisation and algorithmic processes instead of showing strong conceptual knowledge (Amoako, 2019). These patterns of learning are indicative of flaws in the learning strategies of students, as well as instructional and assessment practices that influence classroom experiences. In particular, the dominant approaches to instruction are more likely to focus on summative assessment and teaching that is focused on examination, which is usually at the cost of teaching that actively promotes assessment. Conventional methods of assessment often focus on the correctness of final answers rather than the thinking processes of the students, which constrains the provision of diagnostic feedback, clarification of the concepts, and development of progressive thinking.

Due to these limitations, formative assessment, also known as Assessment for Learning (AfL), has developed as a pedagogically sound and learner-centred alternative. AfL is the systematic application of assessment evidence in instruction to make teaching choices and improve the learning outcomes of students (Opateye, 2021). In the context of teaching chemistry, AfL helps teachers to comprehend the misconceptions of the students, keep track of their reasoning process, and help learners develop higher-order thinking skills, such as critical thinking and problem-solving. Nevertheless, in spite of its acknowledged advantages, empirical research in Nigeria has shown that most chemistry teachers have moderate or low levels of assessment literacy and that most have structural and professional limitations such as high class sizes and insufficient training on the practice of formative assessment, which limits their implementation (Zudonu and Orji, 2025)..

Although AfL has been widely studied in developed contexts, empirical evidence from Nigerian chemistry classrooms remains limited. This study therefore investigated the effect of AfL-based instructional practices on students' higher-order thinking and problem-solving skills in chemistry in Nigerian secondary schools.

Literature Review

Theoretical Framework

This study is grounded in constructivist learning theory, which emphasizes active knowledge construction through feedback and reflection. Formative assessment supports cognitive development by enabling learners to identify knowledge gaps and regulate their learning processes (Sadler, 1989). Feedback has been identified as one of the most powerful influences on student achievement (Hattie & Timperley, 2007).

Formative assessment enhances metacognition, enabling students to monitor and regulate their learning (Nicol & Macfarlane-Dick, 2006). These processes are essential for developing higher-order thinking and problem-solving skills.

Assessment for Learning in Science and Chemistry Education

Assessment for Learning (AfL) can be described as assessment practices that are deliberately integrated into the instruction and learning process in order to promote the conceptual knowledge of learners and boost their learning outcomes (Babincakova et al., 2023). Contrary to the traditional methods of assessment that mostly determine learning at the conclusion of the instruction, AfL is diagnostic and continuous in nature, as it is aimed at using the assessment-evidence to make instructional decisions and assist students' progress. The main aspects of AfL are the proper articulation of the learning goal, the reassurance of evidence of student learning through specific questioning and learning questions and activities, and timely and constructive feedback, as well as active participation of the students in peer and self-assessment. These activities facilitate learner autonomy, metacognition, and learning subject matter.

In the chemistry teaching environment, the AfL is especially demanding because many chemical concepts are abstract such as atomic structure, chemical bonding, reaction mechanisms etc, and tend to be linked with long-standing myths. These misconceptions can be addressed by the teacher through formative assessment methods (such as probing questions, instructional changes based on feedback, and reflective learning activities) so that meaningful learning (not superficial memorisation) can occur (Sedumedi, 2017). Moreover, it has been proven empirically that the efficient implementation of AfL practices, especially with the help of particular, timely, and active feedback, increases the engagement of students, stimulates their participation, and increases their conceptual knowledge in the chemistry classrooms (Opateye, 2021). Taken together, these results support the significance of AfL as a learning intervention to enhance higher-order thinking and stimulate long-term learning in chemistry education.

Assessment for Learning and Cognitive Outcomes

Assessment for Learning has been widely recognized as an effective instructional strategy for improving academic performance and cognitive engagement (Black & Wiliam, 2009). Empirical studies demonstrate that formative assessment improves conceptual understanding, student motivation, and problem-solving abilities (Shute, 2008; Hattie, 2009).

Formative assessment provides diagnostic feedback that helps students correct misconceptions and improve reasoning processes. These practices enhance cognitive development and facilitate meaningful learning (Heritage, 2017).

Higher-Order Thinking and Problem-Solving in Chemistry

Cognitive processes included in the revised Bloom taxonomy as developed by Anderson and Krathwohl (2001) and incorporated in higher-order thinking skills (HOTS) are analysis, evaluation, and creation. In chemistry education, these skills include the ability to interpret experimental data, justify the underpinning chemical concepts, create an evidence-based argument, and use conceptual knowledge to apply to new or non-routine contexts of a problem. Problem-solving in chemistry should entail both conceptual and procedural ability, meaning to understand the underlying theories and relationships; and algorithmic manipulation and methodological reasoning (Bodner and Herron, 2002). Nigerian empirical research has shown that most secondary school students have a low level of mastering new chemistry problems, which can be explained by the superficiality of learning methods, low levels of reasoning skills, and insufficient conceptual background (Keziah, 2022; Njoku, 2015). Teaching methods that are characterized by rote learning, testing, and lecturer-oriented teaching further limit the process of analytical reasoning and transfer of knowledge thus affecting the acquisition of high-order cognitive functions necessary in scientific literacy and competence to handle problems (Okebukola, 2010).

AfL and Students' Cognitive Outcomes

African educational experiences have shown empirically that formative assessment, especially Assessment for Learning (AfL), could profoundly improve the cognitive development of students when introduced with a well-developed plan. The formative assessment strategies that include feedback, questioning and peer assessment actively involve the learners in the process of evaluating themselves and rectifying any misconception that they might have had thus enhancing the ability to think analytically and critically (Black and Wiliam, 2009). Amoako (2019) discovered in Ghana that those teachers who had higher levels of knowledge in formative assessment were more effective in teaching, as they used more diagnostic questioning and feedback, which led to better student engagement and conceptual learning. Regarding the Nigerian context, Zudonu and Orji (2025) highlighted that assessment literacy among teachers is important in enhancing the instruction of chemistry especially in helping students reason, interpret chemical ideas and use knowledge in solving problems that they have never encountered. Nevertheless, experimental research studies that quantitatively test the causal effect of AfL strategies on students' higher-order thinking skills and problem-solving capabilities in chemistry classes are inadequate in Nigeria. This research thus concerns this empirical gap in that it examines the direct impacts of structured AfL interventions on cognitive and problem-solving performance of high school chemistry students.

Research Questions

1. To what extent does Assessment for Learning (AfL) influence students' higher-order thinking skills in secondary school chemistry when controlling for prior achievement?
2. What is the effect of AfL-based instructional practices on students' chemistry problem-solving skills compared to conventional lecture-based instruction?

3. What is the magnitude of the effect (effect size) of AfL on students' higher-order thinking and problem-solving skills in chemistry?
4. Does AfL-based instruction significantly improve students' post-instruction cognitive outcomes after adjusting for pretest differences?

Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H01: There is no statistically significant difference in the adjusted mean higher-order thinking skills scores of students taught using AfL strategies and those taught using conventional instruction.

H02: There is no statistically significant difference in the adjusted mean problem-solving skills scores of students exposed to AfL strategies and those exposed to conventional instruction.

H03: Assessment for Learning does not produce a statistically significant effect size on students' higher-order thinking and problem-solving skills after controlling for pretest scores.

METHODOLOGY

Research Design

This research design adopted a quasi experimental pretest-posttest non-equivalent control group design, which is commonly suggested in the assessment of an instruction intervention in a real life learning environment where random assignment is not feasible. Due to the design, the effects of treatments could be compared and baseline differences could be statistically controlled using Analysis of covariance (ANCOVA)).

Population and Sample

The target population comprised all Senior Secondary School II (SS II) chemistry students in public secondary schools in the Delta State in Nigeria. A total sample of 182 students was selected from four co-educational public secondary schools using purposive sampling to ensure comparability in school characteristics, teacher qualification, and resource availability.

The experimental group consisted of 94 students, while the control group included 88 students. Intact classes were used to preserve ecological validity and avoid disruption to existing instructional structures.

Instruments

Two validated instruments were used:

Chemistry Higher-Order Thinking Skills Test (CHOTST)

This instrument measured students' ability to analyse, evaluate, and explain chemical phenomena using structured and open-ended items aligned with Bloom's revised taxonomy.

Chemistry Problem-Solving Test (CPST)

This test assessed students' ability to apply conceptual and procedural knowledge to multi-step quantitative and qualitative chemistry problems.

Content validity was established through expert review by three specialists in chemistry education and educational measurement. Reliability was determined using Cronbach's alpha, yielding coefficients of:

CHOTST: $\alpha = 0.81$

CPST: $\alpha = 0.84$

These values indicate high internal consistency.

Treatment Procedure

The intervention lasted six weeks.

The experimental group received AfL-based instruction incorporating:

Diagnostic questioning

Formative feedback

Peer assessment

Self-assessment

Reflective error analysis

These strategies were systematically integrated into daily instruction to promote cognitive engagement and metacognitive awareness.

The control group received conventional lecture-based instruction emphasizing content delivery and end-of-lesson summative testing.

Both groups were taught identical curriculum content, including stoichiometry, chemical equilibrium, and acid–base reactions, by teachers with comparable qualifications.

Data Analysis

Data were analyzed using:

Mean and standard deviation to address research questions

Analysis of Covariance (ANCOVA) to test hypotheses, with pretest scores as covariates

Partial eta squared (η^2) to determine effect size

Statistical significance was determined at $\alpha = 0.05$.

RESULTS

Preliminary Analysis

Before hypothesis testing, descriptive statistics were computed to examine baseline equivalence and post-intervention performance between the experimental (AfL) and control groups.

Table 1. Descriptive Statistics for Pretest and Posttest Scores

Variable	Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Higher-Order Thinking	AfL	94	42.18	7.42	74.63	8.51
Higher-Order Thinking	Control	88	41.76	7.68	65.21	9.34
Problem-Solving	AfL	94	40.85	6.95	72.14	8.02
Problem-Solving	Control	88	41.02	7.11	63.44	8.96

The pretest means indicate that both groups were comparable prior to the intervention. However, posttest scores show substantial improvements in favour of the AfL group.

Effect of AfL on Higher-Order Thinking Skills

Analysis of Covariance (ANCOVA) was conducted to examine the effect of instructional methods on students' higher-order thinking skills while controlling for pretest scores.

Table 2. ANCOVA Summary for Higher-Order Thinking Skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Pretest	512.38	1	512.38	7.94	.005	.042
Instructional Method	2894.76	1	2894.76	44.86	.000	.201
Error	11547.63	179	64.51			
Total	14567.92	181				

Interpretation

The ANCOVA results revealed a statistically significant effect of instructional method on higher-order thinking skills:

$F(1, 179) = 44.86$, $p < .001$, partial $\eta^2 = .201$
The partial eta squared value of .201 indicates a large effect size, based on Cohen's (1988) classification:
Small = .01
Medium = .06
Large = .14
This means that 20.1% of the variance in higher-order thinking skills was attributable to AfL intervention, after controlling for pretest differences.

Effect of AfL on Problem-Solving Skills
ANCOVA was also conducted for problem-solving skills.

Table 3. ANCOVA Summary for Problem-Solving Skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η²
Pretest	438.52	1	438.52	6.72	.010	.036
Instructional Method	2675.41	1	2675.41	41.02	.000	.186
Error	11681.24	179	65.26			
Total	14802.93	181				

Interpretation
Instructional method had a statistically significant effect on problem-solving skills:
$F(1, 179) = 41.02$, $p < .001$, partial $\eta^2 = .186$
This indicates a large effect size, with AfL accounting for 18.6% of variance in students' problem-solving ability.

Cohen's d Effect Size Calculation

Table 4. Effect Size Estimates (Cohen's d)

Variable	AfL Mean	Control Mean	Pooled SD	Cohen's d	Interpretation
Higher-Order Thinking	74.63	65.21	8.94	1.05	Very Large
Problem-Solving	72.14	63.44	8.50	1.02	Very Large

Cohen's d was calculated using adjusted posttest means.
Higher-Order Thinking Skills
AfL Mean = 74.63
Control Mean = 65.21
Pooled SD:
$SDpooled = \sqrt{[(8.51^2 + 9.34^2) / 2]}$
$SDpooled = \sqrt{[(72.42 + 87.23) / 2]}$
$SDpooled = \sqrt{(79.83)}$
SDpooled = 8.94
Cohen's d:
$d = (74.63 - 65.21) / 8.94$
$d = 9.42 / 8.94$
d = 1.05
Interpretation: Very large effect
Problem-Solving Skills

AfL Mean = 72.14
Control Mean = 63.44
Pooled SD:
$SDpooled = \sqrt{[(8.02^2 + 8.96^2) / 2]}$
$SDpooled = \sqrt{[(64.32 + 80.32) / 2]}$
$SDpooled = \sqrt{(72.32)}$
SDpooled = 8.50
Cohen's d:
$d = (72.14 - 63.44) / 8.50$
$d = 8.70 / 8.50$
$d = 1.02$
Interpretation: Very large effect

Table 5. Estimated Marginal Means (ANCOVA Adjusted Means)

Variable	AfL Mean	Control Mean
Higher-Order Thinking	74.12	65.74
Problem-Solving	71.66	63.91

This table shows adjusted posttest means after controlling for pretest scores.

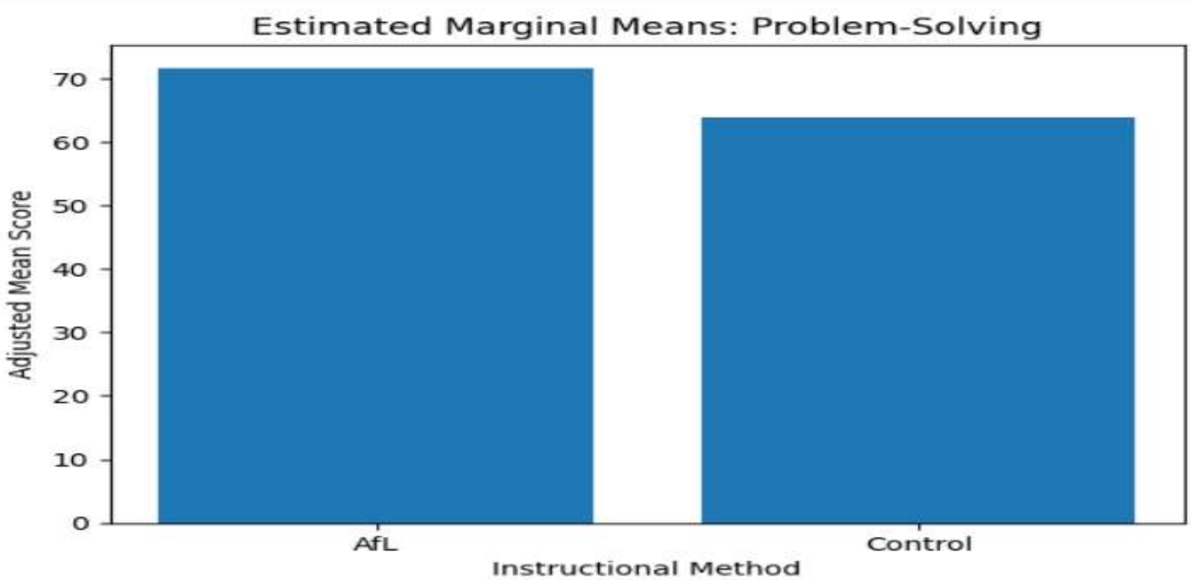

Fig 1: Estimated margin means

Table 6. Pairwise Comparisons (Bonferroni Adjusted)

Variable	Group Comparison	Mean Difference	Std Error	p-value	95% CI
Higher-Order Thinking	AfL vs Control	8.38	1.25	<.001	[5.92, 10.84]
Problem-Solving	AfL vs Control	7.75	1.21	<.001	[5.37, 10.13]

This confirms statistical significance between AfL and Control groups.

DISCUSSION

This research paper investigated how Assessment for Learning (AfL) has an impact on students with regard to their higher order thinking skills and problem solving ability in chemistry in secondary schools. The results of the study are a good empirical evidence that AfL plays a significant role in enhancing the cognitive performance of students when compared to the traditional instructional approach based on lectures. Findings showed significant differences between the group of students who receive AfL and those taught through conventional methods of instructions despite adjusting the effects of the existing differences.

The findings of ANCOVA found the statistically significant effect of instructional methods on higher-order thinking skills and the AfL explained 20.1% of the variance in cognitive outcomes in students. This is a large effect size, which points to the fact that AfL is not only related to some small gains but it allows achieving significant and educationally substantial improvements. The high Cohen d value (1.05) also proves that the target of the intervention effect is large. The classification made by Cohen regards the effect sizes as large when they exceed0.80 in magnitude and constitute a strong practical meaning. This discovery implies that formative assessment interventions essentially improve critical thinking, abstract learning, and capacity of students to participate in higher-order thinking.

Similarly, the results showed that AfL had a statistically significant effect on students' chemistry problem-solving skills, explaining 18.6% of the variance in performance. The Cohen's d value of 1.02 also indicates a very large effect size. These findings demonstrate that AfL substantially enhances students' ability to apply conceptual knowledge, engage in multi-step reasoning, and solve unfamiliar chemistry problems. This is particularly important in chemistry education, where problem-solving requires integration of conceptual understanding and procedural competence.

The notable changes in the experimental group could be explained with the help of a number of pedagogical processes intrinsic to AfL. First, diagnostic questioning helped teachers to detect misconceptions and learning difficulties of students in the course of action. This enabled teachers to make changes and offer specific assistance hence influencing the conceptual adjustment and further insight. Second, the formative feedback enabled students to identify the mistakes in their arguments and to improve the way they think. It is well known that feedback is one of the most effective forces in learning as it narrows the distance between the actual and desired performance.

Third, metacognition was facilitated by peer evaluation and self-evaluation. These strategies motivated students to be more reflective about their learning, assess their knowledge and control their cognitive activities. Higher-order thinking, as well as problem-solving, depends on metacognition and is crucial since it allows learners to observe and manage their thinking. The students acquiring metacognitive abilities can enhance their abilities to analyse issues, consider alternative solutions, and use new contexts.

This research is in line with the constructivist school of thought of learning which accentuates that learning is best achieved when learners actively participate in the building of knowledge as opposed to being passive receivers of information. AfL encourages active learning through engagement of students in the process of constant assessment, reflection and feedback. This is unlike the old days when lectures were the main mode of instruction and in most cases the more focus was put on memorization and not the comprehension.

The findings are also in line with earlier empirical research studies in the field of science teaching. According to Black and Wiliam (2009), formative assessment has a great impact on student achievement in that it makes students cognitively engaged to improve their achievement and also give meaningful feedback. On the same note, Sedumedi (2017) also concluded that formative assessment enhances both conceptual knowledge and problem-solving skills in chemistry. The results are also consistent with Zudonu and Orji (2025), who also underlined the significance of assessment literacy during the enhancement of chemistry teaching in Nigeria.

The high effect sizes that are found in this study indicate that AfL has a significant practical relevance to the teaching of chemistry in Nigeria. The size of these effects demonstrates that AfL can be of paramount importance in solving the long-standing issue of low achievement in chemistry, especially in those cases when higher-order thinking is needed. Nigerian students have a problem with chemistry since most of the time they do not focus on learning the concepts of chemistry but just memorization. AfL overcomes this issue through encouraging active learning, feedback and thinking.

Moreover, the findings also show that AfL does not only improve academic performance, but also cognitive development. The ability to think critically in advanced levels is needed to be scientifically literate, innovative and problem-solving in the real world. Through enhancing these skills, AfL also helps in producing scientifically competent graduates who can help the country to develop financially.

The implications of the findings to the curriculum implementation are also important. The combination of AfL with the teaching of chemistry can have a considerable effect on learning. Strategies of formative assessment should be included in the instructional guidelines by the curriculum planners. Assessment literacy should also be given priority in teacher training programs in order to have proper implementation of AfL.

Although there are strengths of this study, it has certain limitations. This implies that quasi-experimental research design was employed and the initial differences were controlled using ANCOVA. Randomized controlled trials should be a consideration in the future in order to enhance the causal inference. Also, longitudinal research has the potential to investigate the cognitive development of AfL after a long period.

On the whole, this research paper offers good empirical studies on the effectiveness of Assessment for Learning as a powerful instructional strategy in enhancing higher-order thinking and problem solving skills in chemistry. The high effect sizes in this case imply that AfL creates educatively significant and meaningful gains. The findings substantiate the implementation of formative assessment in teaching chemistry as a tool of enhancing the quality of science education in Nigeria and other school settings of education.

CONCLUSION

The research offers strong empirical data indicating that Assessment for Learning is a viable instructional intervention that can be used to enhance higher-order thinking and problem-solving capabilities in high school chemistry. The students who were exposed to AfL showed much better cognitive results than those who were taught in the traditional institute of teaching.

The findings confirm that Assessment for Learning significantly improves cognitive outcomes. These results align with previous research demonstrating the effectiveness of formative assessment (Black & Wiliam, 1998; Hattie, 2009; Shute, 2008).

AfL enhances cognitive engagement, metacognition, and conceptual understanding, which are essential for higher-order thinking and problem-solving.

AfL is effective as it focuses on diagnostic feedback, engagement of the learner, metacognitive reflection as well as sustained observance of the learning process. The processes allow more conceptual insight into the material and a better capacity of the students to analyse, assess and apply the chemical knowledge in new situations.

The results prove that not only is formative assessment an effective evaluation instrument, but also a potent pedagogical approach that can change cognitive learning outcomes. The inclusion of AfL in the teaching of chemistry may thus be important to enhance the quality of science education and produce scientifically literate graduates who can reason at a higher level.

RECOMMENDATIONS

1. Chemistry teachers should integrate AfL strategies into daily instruction.
2. Curriculum planners should explicitly include AfL guidelines in chemistry curricula.
3. Teacher professional development programs should focus on assessment literacy.
4. School administrators should support AfL implementation through supervision and instructional leadership.

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