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Students' involvement in learning: Formative assessment as a predictor of STEM competencies development

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Abstract

The development of science and technology skills in primary education is essential for fostering critical thinking and problem-solving abilities. However, limited research explores the specific role of formative assessment in shaping these competencies. This study addresses this gap by examining how formative assessment predicts students' proficiency in scientific research methods, problem-solving through technological solutions, and the ability to explain the physical world using scientific knowledge. Using a correlational design, data were collected from a probabilistic sample of 116 students. The reliability of the assessment tools was confirmed, and findings indicate that formative assessment is a strong predictor of overall science and technology competencies. The final model demonstrated a superior fit compared to baseline models, underscoring the importance of formative assessment in enhancing learning outcomes. These results emphasize the need for educators to integrate effective assessment strategies to support students' development of science and technology skills in primary education.

Keywords*:* Academic achievement; formative assessment; formative evaluation; learning skills development; self-regulation.

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1. INTRODUCTION

Formative assessment has great potential to improve the quality of both student and teaching teaching-learning processes (Boström & Palm 2023; Andreassen & Malling, 2019; Cagasan et al., 2020; Cañadas, 2023; Chan, 2021; Tan, 2019; Hoepner & Hemmerich, 2020; López, 2011; Msosa et al., 2021; Narciss et al., 2020; Ismail et al., 2022). It is usually suggested that assessments unfold at a permanent and methodical pace, while monitoring is used to assess learning and the progress of competencies development (Kang & Lam 2024).

We minimally define educational competencies as the knowledge required to achieve the goals set forth by certain performance criteria (e.g., usually, knowing how to be, knowing how to know, and knowing how to do). They are based on the appraisal of certain metacognitive capacities such as self-guidance, choice, and cognitive leadership (Mihwa et al., 2020; Wafubwa & Csikos, 2021). They also imply regulation and self-regulation, that is, the adaptation of activities to the needs and difficulties that are constantly found in the learning process (Ngugi & Goosen, 2018; Sadi, 2017; Schunk & Zimmerman, 1989; Zimmerman, 2013). Furthermore, pedagogical strategies and models that promote students' self-learning are coherent with international crediting systems such as the ECTS and are widely accepted in higher education.

One of the most pressing themes found in the literature was the student's involvement in the assessment, due to how beneficial it is for the development of generic and specific competencies, as well as at qualitatively higher levels of learning (Zenouzagh Mohammadi et al., 2025; Croft et al., 2019; Kleib & Nagle, 2018; Krstikjt et al., 2022; Lamada et al., 2022; Pallares et al., 2022; Perdana, 2021; Purnomo et al., 2022; Shara et al., 2022; Webb et al., 2022). However, there are few studies on the predictive value of formative assessment in the development of science and technology skills (Cigdem et al., 2024; Moed-Abu Raya & Olsher, 2024). Also, our literature review allows us to affirm that the trend is towards quasi-experimental studies, to the detriment of non-linear correlational studies. For this reason, a study like this is relevant and necessary because it fills a gap in academic and scientific production.

Formative assessments are pivotal to the implementation and realization of the competency-based approach in science and technology education. This has been addressed before in numerous studies. In Peru, Pajuelo et al. (2021) found that formative assessment has a favorable impact on autonomous learning, while Medina and Nagamine (2019) found that autonomous learning strategies have an appreciable explanatory power on reading comprehension of science and technology. The trend is also visible in other developing countries. In East Europe, the assessment of scientific inquiry has been found effective in developing metacognitive skills and educational outcomes in the sciences (Babincaková et al., 2020; Skoda et al., 2016; Sotaková et al., 2020). Similarly, in Asia, Syifahayu (2017), Ozan and Kincal (2018), and Kültur and Kutlu (2021) have found significant experimental results in broader STEM education, comparing monitored groups to those not assessed.

There are known mechanisms guiding this link. Sadler (1989), an Australian specialist, challenged the common perception that giving feedback was the starting point of assessment: instead, teachers need precise performance criteria, and improvement strategies must be shared with students during the assessments. According to Shepard and Brennan (2006), this model was explained and developed by Coffey et al. (2001) in a report on science assessment in the classroom. They built the learning assessment process with three core questions: 1) Where are you trying to go? 2) Where are you now? 3) How can you get there? Competencies-wise, we align ourselves with the socioformative approach literature, which resonates with Atkins and Sadler's ideas through the pedagogical use of interaction (Tobón et al., 2015).

In Peru, the development of formative assessment systems is still in its early stages, with most efforts concentrated in higher education (Beriche & Medina, 2021; Bizarro et al., 2019; Leandro et al., 2022; Mollo & Medina, 2020; Quiñones et al., 2021; Torres et al., 2021; Valdivia & Fernández, 2020). It is important to note that the commonly accepted approach in this context lacks integrated elements of the knowledge construction process. A prevailing view is that educators should first teach and then assess what has been learned (Jorba & Sanmartí, 1994). This separation is illogical. Another commonly held belief that warrants reevaluation is the equivalence between assessment and grading. This conceptual confusion persists across many teaching sectors worldwide (McCarthy et al., 2025; Bulunuz, 2019; Granberg et al., 2021; Kultur & Kutlu, 2021).

1.1. Purpose of study

The purpose of this study is to examine the development of formative assessment systems in higher education in Peru, with a focus on addressing the lack of integration between teaching and assessment. Additionally, the study aims to explore the prevalent misconception of equating assessment with grading and its impact on teaching practices.

Three hypotheses were proposed regarding the measured competencies in science and technology: (H1) inquiries through scientific methods to build knowledge; (H2) explaining the physical world based on knowledge about living beings, matter and energy, biodiversity, Earth, and the Universe; and (H3) designing and building technological solutions to solve problems in the surrounding environment.

2. METHOD AND MATERIALS

2.1. Research design

A multinomial logistic multivariate design was employed to investigate the relationships between formative assessment and the development of science and technology skills (Creswell & Creswell, 2018). The presence of formative assessment served as the response variable, with scientific and technological skills as the predictors.

2.2. Participants

A simple probabilistic sample was randomly selected from a population of 165 basic education students at a public institution in the urban district of Independencia (Lima, Peru). The final sample consisted of 116 students (Hernández & Mendoza, 2018).

2.3. Data collection tools

The instruments used for data collection demonstrated strong reliability, with Cronbach's alpha values of α = 0.894 for formative evaluation and α = 0.836 for science and technology competencies. The questionnaire for the independent variable was based on Cerón et al. (2020).

2.4. Statistical analysis

The Kolmogorov-Smirnov normality tests (Table 1) revealed that both the formative assessment variable and its dimensions, as well as the science and technology skills and their dimensions, did not follow a normal distribution. As a result, a nonparametric test, specifically multinomial logistic regression, was applied.

Table 1
Normality tests

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Formative Assessment	,274	116	,000
Grading-related	,320	116	,000
Proactive	,288	116	,000
Interactive	,307	116	,000
Metacognitive	,301	116	,000
Retroactive	,305	116	,000
Adjusted	,299	116	,000
Academic Achievement (joint score)	,242	116	,000
Inquires through scientific methods	,273	116	,000
Explica el mundo físico	,249	116	,000
Explains the physical world scientifically	,254	116	,000

a. Lilliefors Significativity correction

3. RESULTS

3.1. Descriptive results

Figure 1 shows the descriptive statistics of the formative assessment. The medium level has been predominant in almost all its dimensions: related to grading (59%), proactive (49%), interactive (54%), and adjusted (59%); the highest level was the main one in the retroactive formative assessment (47%).

Figure 1

Formative assessment levels and dimensions

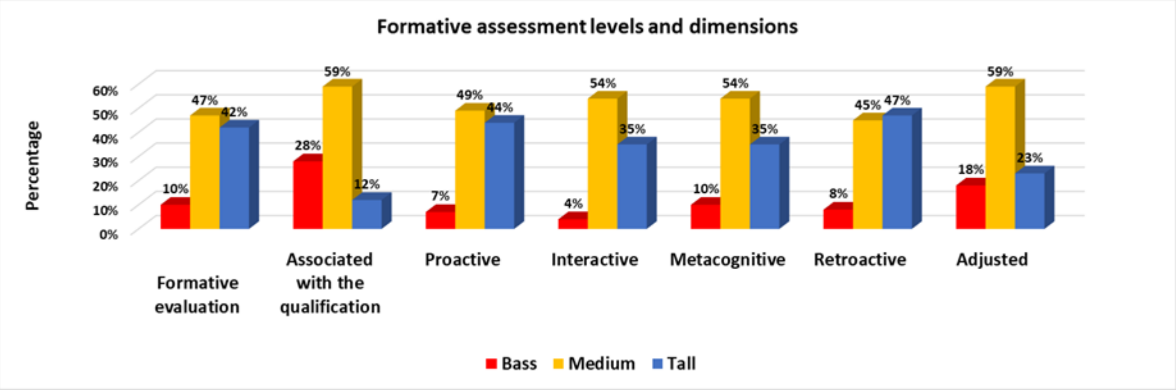
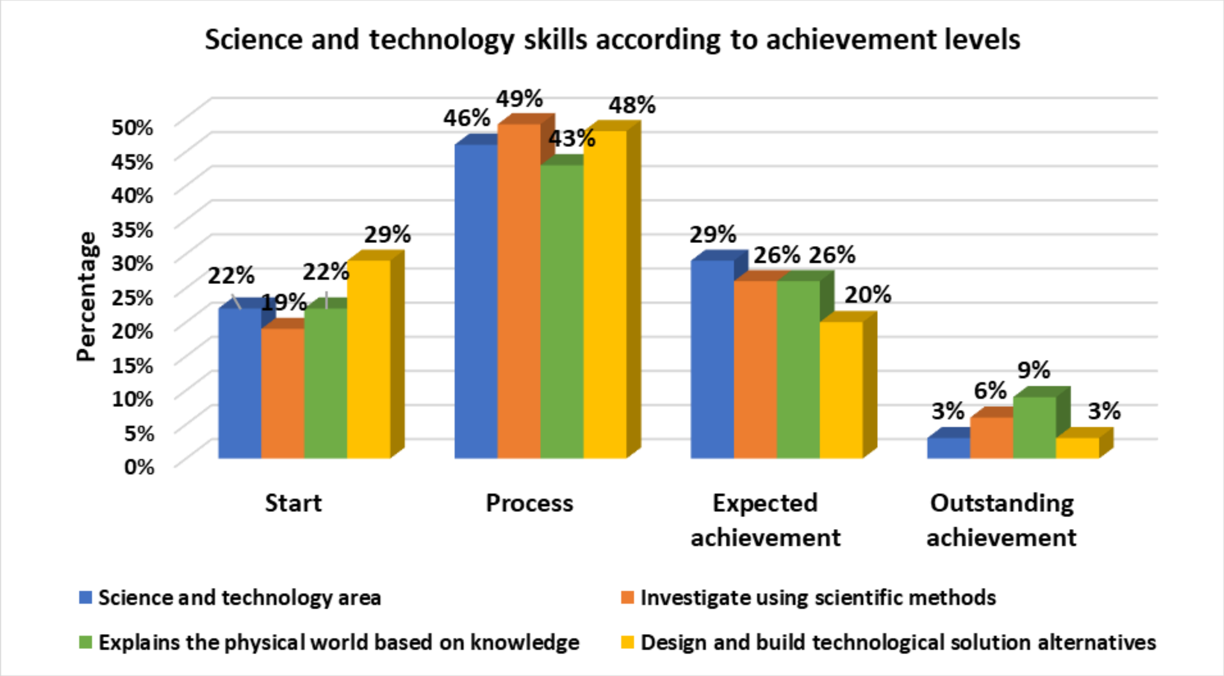


Figure 2 shows evidence that a low formative assessment (In Process) was predominant both in general (46%) and in its competencies: inquiries through scientific methods (49%), explaining the physical world based on scientific knowledge (43%), and designs and builds technological solutions (48%).

Figure 2

Science and technology skills according to achievement levels



3.2. Multinomial logistic modelling

Table 2 shows that the final multinomial logistic regression model fits the data set of the formative evaluation variable and the area of science and technology with each of its dimensions (Sig. <0.001).

Table 2
Model fit information

Variables	Model	Log-Likelihood -2	Chi-Squared	df	Sig.
Academic Achievement (joint score)	Intercept-only	128,374			
	Final	11,355	117,020	6	<0,001
Inquires through scientific methods	Intercept-only	79,078			
	Final	20,553	58,525	6	<0,001
Explains the physical world scientifically	Intercept-only	72,453			
	Final	22,7545	49,698	6	<0,001
Designs and builds technological solutions.	Intercept-only	88,852			
	Final	16,420	72,431	6	<0,001

Table 3 presents likelihood ratios, where it is observed that the sig. <0.001 in each of them: there is statistical evidence that formative assessment influences science and technology skills (Sig.<0.001). Also, there is statistical evidence that the formative assessment influences the competence inquiries through scientific methods (Sig. <0.001). In addition, there is statistical evidence that formative assessment influences competence and explains the physical world based on knowledge (Sig. <0.001). Finally, there is statistical evidence that formative assessment influences the competence to design technological solution alternatives (Sig.<0.001).

Table 3
Likelihood ratios test

		Model-fit criteria	Likelihood ratios test		
Variables	Model	Log-Likelihood -2	Chi-Squared	df	Sig.
Academic Achievement (joint score)	Intercept-only	11,355[a]	0,000	0	.
	Formative Assessment	128,374	117,020	6	<0,001
Inquires through scientific methods	Intercept-only	20,553[a]	0,000	0	.
	Formative Assessment	79,078	58,525	6	<0,001
Explains the physical world scientifically	Intercept-only	22,754[a]	0,000	0	.
	Formative Assessment	72,453	49,698	6	<0,001
Designs and builds technological solutions.	Intercept-only	16,420[a]	0,000	0	.
	Formative Assessment	88,852	72,431	6	<0,001

The chi-square statistic is the -2 log-likelihood difference between the final model and the reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all the parameters of this effect are 0.

Table 4 presents the results of the Pseudo R-squared test. Of the three statistics (Cox and Snell, Nagelkerke, and McFadden), the highest value (Nagelkerke coefficient) was assumed as a decision rule. There is statistical evidence that the prediction of the response variable for each of the models is good. We conclude that formative assessment predicts 70.8% of the acquired science and technology skills. Also, formative assessment predicts 43.7% of the scientific inquiry competence and 52.1% of the competence to design and build technological solution alternatives. Plus, formative assessment negatively predicts the ability to explain the physical world based on knowledge.

Table 4

Pseudo R-squared test

Variables	Cox-Snell	Nagelkerke	McFadden
Academic Achievement (joint score)	0,635	0,708	0,444
Inquires through scientific methods	0,396	0,437	0,213
Explains the physical world scientifically	0,348	0,395	0,170
Designs and builds technological solutions	0,464	0,521	,282

The model correctly classifies 70.7.1% of the information that is considered an acceptable regression value (Table 5). This contrasts with models with intercepts. The model that relates formative assessment and the skill to design and build technological solutions correctly classifies 61.2% of the data. Formative assessment and scientific inquiry correctly classify 58.6% of it, while formative assessment and explaining the physical world based on knowledge predict 49.1%.

Table 5

Clasiffication table

	Observed	Predicted				
		Basic	In progress	Expected achievement	Strong achievement	Total, predicted (%)
HG	Basic	12	13	0	0	48,0%
	In progress	0	37	18	0	67,3%
	Expected achievement	0	0	33	0	100,0%
	Strong achievement	0	0	3	0	0,0%
	Total, observed (%)	10,3%	43,1%	46,6%	0,0%	70,7%
HE1	Basic	9	11	2	0	40,9%
	In progress	3	34	20	0	59,6%
	Expected achievement	0	5	25	0	83,3%
	Strong achievement	0	0	7	0	0,0%
	Total, observed (%)	10,3%	43,1%	46,6%	0,0%	58,6%
HE2	Basic	9	15	0	0	37,5%
	In progress	3	48	0	0	94,1%
	Expected achievement	0	30	0	0	0,0%
	Strong achievement	0	11	0	0	0,0%
	Total, observed (%)	10,3%	89,7%	0,0%	0,0%	49,1%
HE3	Basic	12	20	0	0	37,5%
	In progress	0	59	0	0	100,0%
	Expected achievement	0	22	0	0	0,0%
	Strong achievement	0	3	0	0	0,0%
	Total, observed (%)	10,3%	89,7%	0,0%	0,0%	61,2%

Note: HG: Formative assessment and joint science and technology skills scores; HE1: Formative assessment and inquiries through scientific methods; HE2: Formative assessment and explains the physical world scientifically; HE3: Formative assessment and Designs and builds technological solutions.

Table 6 shows the parameter estimation results, including the Wald coefficient associated with each test. It reveals that there exists association and dependence between the response variable and each skill. It is shown that the formative assessment is a predictor of science and technology skills in basic education students.

Table 6

Parameter estimates of multinomial correlation

			B	Std. Dev.	Wald	df	Sig.	Exp(B)
HG	Basic	Intercept	-17,036	2889,163	0,000	1	0,995	
		[Formative Assessment=1]	40,851	8296,547	0,000	1	0,996	551336618305812000,000
		[Formative Assessment=2]	37,594	8577,599	0,000	1	0,997	21234414282466600,000
		[Formative Assessment=3]	0c			0		
	In progress	Intercept	1,792	0,624	8,255	1	0,004	
		[Formative Assessment=1]	1,117	0,000		1		3,056
		[Formative Assessment=2]	19,813	8076,382	0,000	1	0,998	402237156,655
		[Formative Assessment=3]	0c			0		
	Expected Achievement	Intercept	2,398	0,603	15,812	1	0,000	
		[Formative Assessment=1]	0,000	0,000		1		1,000
		[Formative Assessment=2]	0,000	8435,504	0,000	1	1,000	1,000
		[Formative Assessment=3]	0c			0		
HE1	Basic	Intercept	-1,253	0,802	2,441	1	0,118	
		[Formative Assessment=1]	22,761	0,997	520,949	1	0,000	7671834354,307
		[Formative Assessment=2]	19,663	2999,291	0,000	1	0,995	346336172,515
		[Formative Assessment=3]	0c			0		
	In progress	Intercept	1,050	0,439	5,715	1	0,017	
		[Formative Assessment=1]	19,360	0,000		1		255727811,810
		[Formative Assessment=2]	18,489	2999,291	0,000	1	0,995	107049362,414
		[Formative Assessment=3]	0c			0		
	Expected Achievement	Intercept	1,273	0,428	8,862	1	0,003	
		[Formative Assessment=1]	0,182	7538,461	0,000	1	1,000	1,200
		[Formative Assessment=2]	16,349	2999,291	0,000	1	0,996	12594042,637
		[Formative Assessment=3]	0c			0		
HE2	Basic	Intercept	-2,303	1,049	4,820	1	0,028	
		[Formative Assessment=1]	23,913	1,221	383,815	1	0,000	24289048779,112
		[Formative Assessment=2]	4,942	1,474	11,246	1	0,001	140,000
		[Formative Assessment=3]	0b			0		
	In progress	Intercept	0,788	0,381	4,274	1	0,039	
		[Formative Assessment=1]	19,724	0,000		1		368015890,593
		[Formative Assessment=2]	2,470	1,088	5,152	1	0,023	11,818
		[Formative Assessment=3]	0b			0		
		Intercept	0,742	0,384	3,729	1	0,053	

		[Formative Assessment=1]	0,261	9947,632	0,000	1	1,000	1,299
	Expected Achievement	[Formative Assessment=2]	1,455	1,122	1,683	1	0,195	4,286
		[Formative Assessment=3]	0[b]			0		
		Intercept	0,000	0,816	0,000	1	1,000	
	Basic	[Formative Assessment=1]	23,100	10375,938	0,000	1	0,998	10765986779,732
		[Formative Assessment=2]	20,690	7542,534	0,000	1	0,998	967130282,235
		[Formative Assessment=3]	0[c]			0		
		Intercept	2,197	0,609	13,035	1	0,000	
		[Formative Assessment=1]	0,782	12380,577	0,000	1	1,000	2,185
HE3	In progress	[Formative Assessment=2]	19,125	7542,534	0,000	1	0,998	202275614,585
		[Formative Assessment=3]	0[c]			0		
		Intercept	1,946	0,617	9,940	1	0,002	
	Expected Achievement	[Formative Assessment=1]	0,047	0,000		1		1,048
		[Formative Assessment=2]	15,911	7542,534	0,000	1	0,998	8127145,229
		[Formative Assessment=3]	0[c]			0		

Note: HG: Formative assessment and joint science and technology skills scores; HE1: Formative assessment and inquires through scientific methods; HE2: Formative assessment and explains the physical world scientifically; HE3: Formative assessment and Designs and builds technological solutions
a. Reference category: Strong Achievement
b. Value is defined as system loss.
c. Redundant parameters, taken as 0.

We developed an additional confirmatory factor analysis. Table 7 shows a significative relationship between the variables (p <0,05). Factor analysis shows estimators bigger than 0.7, revealing strong and very strong relationships.

Table 7

Covariance between response variable dimensions (formative assessment)

		Statistic	SE	Z	p
Grading-related	Grading-related	1.000[a]			
	Proactive	1.071	0.1434	7.47	< .001
	Interactive	1.030	0.1179	8.74	< .001
	Metacognitive	0.792	0.1393	5.69	< .001
	Retroactive	1.017	0.1145	8.88	< .001
	Adjusted	0.773	0.1467	5.27	< .001
Proactive	Proactive	1.000[a]			
	Interactive	0.964	0.1011	9.54	< .001
	Metacognitive	0.803	0.1082	7.43	< .001
	Retroactive	0.935	0.0975	9.59	< .001
	Adjusted	0.802	0.1246	6.44	< .001
Interactive	Interactive	1.000[a]			
	Metacognitive	0.890	0.0774	11.49	< .001
	Retroactive	1.069	0.0607	17.61	< .001
	Adjusted	0.874	0.0962	9.08	< .001
Metacognitive	Metacognitive	1.000[a]			
	Retroactive	0.819	0.0791	10.35	< .001
	Adjusted	0.838	0.0917	9.14	< .001
Retroactive	Retroactive	1.000[a]			
	Adjusted	0.801	0.1027	7.80	< .001
Adjusted	Adjusted	1.000[a]			

[a] Fixed parameter

It is also observed that all the items present factor loadings greater than 0.30 (estimator), according to McDonald the coefficients represent the degree of relationship between the construct and the dimension that show appropriate and acceptable values. Table 8 presents the factor loadings for the dimensions of formative assessment.

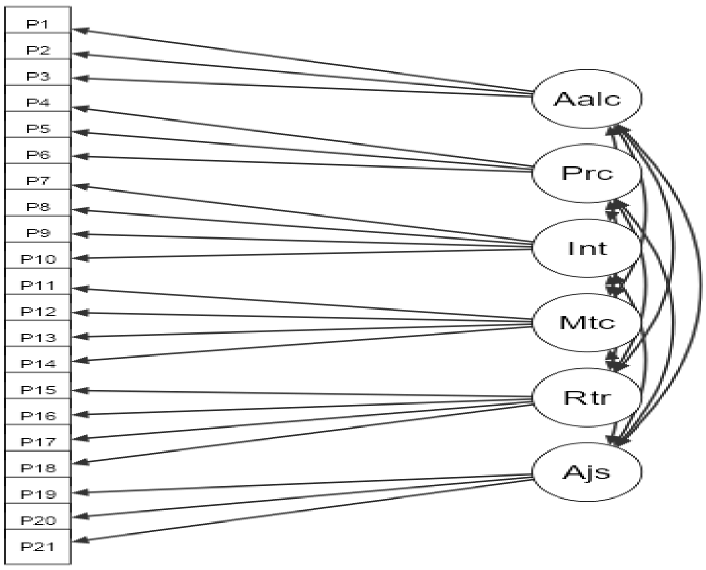
Table 8

Factor loadings of formative assessment dimensions

Factor	Item	Estimator	Std. Err.	Z	p
	P1	0.395	0.1079	3.66	< .001
Grading-related	P2	0.529	0.1292	4.10	< .001
	P3	0.681	0.1124	6.06	< .001
	P4	0.691	0.1326	5.21	< .001
Proactive	P5	0.587	0.1166	5.04	< .001
	P6	0.665	0.1132	5.88	< .001
	P7	0.598	0.1115	5.37	< .001
Interactive	P8	0.782	0.0973	8.04	< .001
	P9	0.452	0.1126	4.01	< .001
	P10	0.650	0.0905	7.17	< .001
	P11	0.593	0.0969	6.11	< .001
Metacognitive	P12	0.649	0.1130	5.74	< .001
	P13	0.584	0.1052	5.55	< .001
	P14	0.831	0.1048	7.92	< .001
	P15	0.712	0.0934	7.62	< .001
Retroactive	P16	0.808	0.1015	7.96	< .001
	P17	0.541	0.0977	5.53	< .001
	P18	0.534	0.0989	5.40	< .001
	P19	0.488	0.1048	4.65	< .001
Adjusted	P20	0.538	0.0936	5.76	< .001
	P21	0.736	0.1084	6.79	< .001

Figure 3

Flowchart of dimensions of formative assessment



Note. Aalc: Asociation to grading; Prc: Proactive; Int: Interactive; Mtc: Metacognitive; Rtr: Retroactive; Ajs: Adjusted. P1-P21 are the assessment items considered.

4. DISCUSSION

Assessing from a formative perspective aims to promote better learning outcomes. When evaluation is approached theoretically and conceptually, it emphasizes the regulation of learning, which is considered by many to be an indicator of success. However, in practice, some educators limit regulation to content coverage and often overemphasize the role of the teacher in this process. In contexts with limited pedagogical knowledge, educators tend to avoid transferring decision-making power regarding the learning process to students. As a result, students in developing countries often lack sufficient opportunities for autonomous learning.

This study aimed to examine the impact of formative assessment on the development of science and technology skills in basic education students. The study's modest objectives were met, and the hypotheses were supported by empirical evidence. One of the key findings is that formative assessment significantly influences the achievement of complex performances related to science and technology. This finding aligns with existing literature in developing countries, which highlights the connection between formative assessment and local educational expectations. While not all reviewed studies used the same methodology, quasi-experimental results suggest strong relationships, as formative assessment strategies facilitate a qualitative shift, transforming assessment from merely measuring learning to assessing for and as learning (Ministry of Education of the Republic of Peru, 2017).

Formative assessment, as a supportive activity, helps students identify what they are trying to learn, assess their progress, and understand how they can improve (Fraile et al., 2020; Panadero et al., 2018). This approach is aligned with the Bologna Process framework, which distinguishes evaluation from grading and emphasizes its integration into the teaching-learning process (Fraile et al., 2017). By focusing on the learning process rather than the product, the educational system shifts its emphasis. This perspective, grounded in humanistic and critical theory, suggests that when both the content and methods of assessment are scrutinized, the pedagogical work itself is being evaluated. Self-assessment and peer assessment, as tools for empowering students, enable them to self-regulate their learning, yielding benefits on interpersonal, motivational, and emotional levels. These outcomes also complement socio-constructivist approaches (Fraile et al., 2021; Panadero et al., 2016).

The results of this study have limitations. First, the sample size is small compared to earlier studies. Additionally, the sample is confined to urban, public, and primary education populations. However, the methodology provides sufficient foundation for replication with larger samples in diverse socioeconomic and cultural contexts. Future research could include samples from private educational institutions and rural areas to achieve more representative samples of the Peruvian educational reality and allow for a broader discussion of the results. Furthermore, while this study focused on science and technology skills, it would be valuable to examine competencies in other curricular areas, such as communication, mathematics, and social sciences.

5. CONCLUSION

Self-regulation, metacognitive skills, comprehensiveness, and skill development are among the most significant educational challenges of the 21st century. This research posits that one of the most relevant and effective strategies to address these challenges is the implementation of formative assessment methods. The findings indicate that formative assessment predicts the development of scientific and technological skills in school education, analyzed through a multinomial logistic multivariate correlation approach.

Although the results are based on a small urban high school sample from a developing country, they align with quasi-experimental findings from Eastern Europe and Asia. Reflecting on these results and sharing proposals related to formative assessment in scientific literacy may provide valuable tools for future-oriented education, particularly in developing countries.

Conflict of Interest: The authors declare no conflict of interest.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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