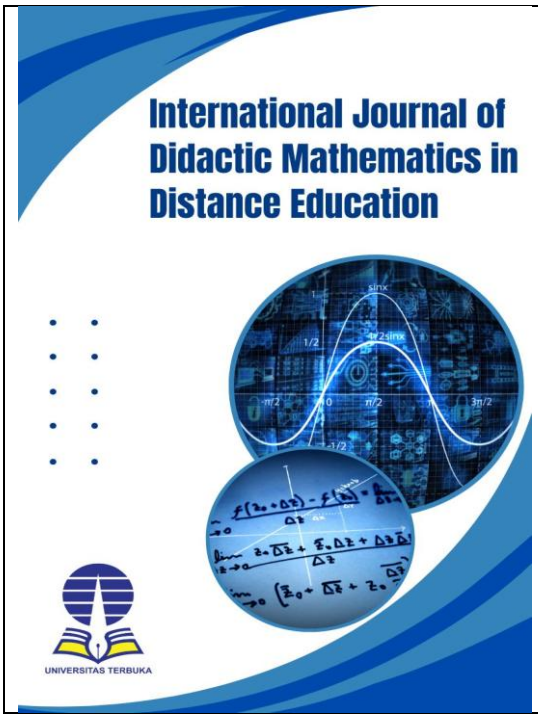
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Post-pandemic online learning in Indonesian Mathematics Education: the perception-achievement relationship

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Post-pandemic online learning in Indonesian Mathematics Education: the perception-achievement relationship

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Abstract
The COVID-19 pandemic accelerated online learning adoption in higher education, yet its longitudinal impact on mathematics education remains underexplored. This study investigated how mathematics education students' perceptions of online learning evolved between pandemic and post-pandemic periods and examined the relationship between these perceptions and academic achievement. Using an ex post facto quantitative design, we surveyed 157 undergraduate students at the Department of Mathematics, Universitas Negeri Makassar, Indonesia. Participants were stratified into two cohorts: during-pandemic and post-pandemic learners. We assessed four dimensions, resilience, infrastructure support, learning activities, and instructor competence, using structured questionnaires, complemented by semi-structured interviews for depth. Independent t-tests and linear regression analyses were conducted. Results revealed significantly more favorable perceptions among post-pandemic students, particularly regarding confidence, infrastructure adequacy, and interactive engagement. Students valued flexibility, access to materials, and opportunities for self-regulated learning. However, persistent challenges included comprehension difficulties and concerns about assessment fairness. Linear regression analysis indicated a statistically significant but weak positive relationship between perceptions and GPA (R^2=.05), suggesting that while perception influences academic performance, it explains only 5% of achievement variance. These findings highlight that improvements in digital infrastructure and instructor competence enhanced student engagement, yet pedagogical strategies for conceptual understanding and authentic assessment require further development. The study contributes to understanding the evolution of online learning effectiveness beyond crisis contexts and underscores the importance of sustained investment in blended learning environments for mathematics education.

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1. Introduction

Mathematics is a deductive science that progresses from basic to complex ideas, characterized by logical structure and precise symbolic representation. It functions not only as a tool for systematic reasoning but also as a universal language for scientific communication (National Council of Teachers of Mathematics [NCTM], 2000). As a core discipline, mathematics supports the advancement of other sciences and equips learners with problem-solving skills applicable to real-life situations (Kilpatrick et al., 2001).

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However, despite its pivotal role, mathematics is often perceived as a difficult subject due to its abstract nature and procedural demands (Zakaria & Nordin, 2008).

With the rapid development of technology, teaching and learning are no longer confined to physical classrooms. Online platforms such as Zoom and Google Meet now enable remote learning environments. The effectiveness of such online learning, however, largely depends on educators' digital competence and the availability of engaging, technology-supported instructional media (Hodges et al., 2020; Isnawan et al., 2024; Prasetya et al., 2025; Rasilah et al., 2024). As these technologies became integral to education, many universities around the world began integrating online and blended learning approaches to ensure instructional continuity during crises such as the COVID-19 pandemic. This shift not only transformed pedagogical practices but also prompted educators and institutions to re-evaluate students' learning experiences and attitudes toward digital learning environments.

The Department of Mathematics, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Negeri Makassar (UNM), implemented online learning during the COVID-19 pandemic using various digital tools. In this context, assessing students' perceptions of e-learning, both during and after the pandemic—has become essential, particularly for mathematics education students whose learning requires high levels of abstract and logical reasoning. These perceptions, encompassing factors such as resilience, learning infrastructure, student engagement, and lecturer competence, provide valuable insights into the effectiveness of online learning and its influence on academic performance. Understanding these perspectives can guide the enhancement of instructional design and digital pedagogy in the post-pandemic educational landscape.

Over the past decade, research on students' perceptions of online learning and its relationship to academic achievement has expanded significantly. Numerous studies have found that the transition to online learning during the COVID-19 pandemic negatively affected student performance, especially in subjects requiring high-level reasoning such as mathematics, due to reduced interaction, technological barriers, and psychological stress (Adedoyin & Soykan, 2020; Aristovnik et al., 2020). Other studies reported that positive perceptions of online learning, such as satisfaction, readiness, and perceived quality, were strongly correlated with student engagement and learning outcomes (Almahasees et al., 2021; Dhawan, 2020; González-Ramirez et al., 2021).

Specific to mathematics education, several researchers highlighted that the abstract nature of mathematical concepts and the need for visual or manipulative representations make online instruction particularly challenging. Students often experience difficulties in understanding mathematical reasoning when face-to-face interaction and real-time scaffolding are limited (Crawford & Cifuentes-Faura, 2022; Kaur et al., 2021). However, well-designed digital learning environments, those integrating interactive visual tools and collaborative activities, can mitigate these challenges and enhance conceptual understanding (Kumar et al., 2021; Nugroho et al., 2025).

In the context of teacher education, studies on preservice mathematics teachers emphasize that online learning promotes digital competence and pedagogical flexibility, yet also requires substantial institutional support and mentoring to ensure effective learning outcomes (Rapanta et al., 2020; Sari et al., 2024). These findings underscore that students' perceptions are multidimensional, shaped by both internal factors (such as motivation and self-regulation) and external conditions (such as infrastructure and lecturer guidance).

Despite these advancements, several research gaps remain. First, most previous studies were conducted in general higher education contexts or in Western countries, with limited evidence from Indonesian institutions, particularly within mathematics education programs where abstract reasoning is central to learning. Second, comparative studies that analyze students' perceptions of online learning during and after the pandemic remain scarce. Most research focuses only on the emergency remote learning phase, overlooking long-term adaptations and their implications for academic achievement. Third, the constructs used to measure perception vary widely across studies, often focusing narrowly on satisfaction or readiness, while neglecting integrated dimensions such as resilience, engagement, and lecturer competence. Finally, few studies specifically examine how these perceptions correlate with actual

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academic performance among mathematics education students, especially those preparing for teaching careers in digitally mediated environments.

Given these considerations, this research aims to examine how mathematics education students, who often face challenges in learning abstract concepts, adapt to online learning environments that demand both resilience and digital readiness. By exploring both cognitive and contextual dimensions, this study seeks to provide empirical evidence on how perceptions toward online learning influence academic achievement in mathematics education at FMIPA UNM.

Based on the background above, this study seeks to address the following research questions:

a) What is the description of mathematics education students' perceptions in the Department of Mathematics, FMIPA UNM, toward online learning during and after the pandemic?
b) Is there a significant relationship between students' perceptions of online learning and their academic achievement during and after the COVID-19 pandemic?

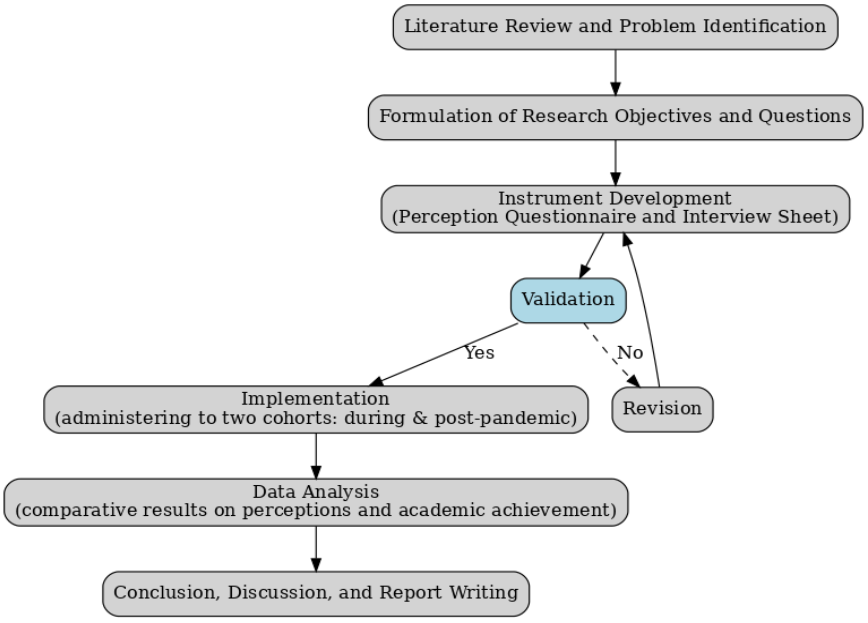
2. Methods

This research employs a quantitative approach using an ex post facto design. The study aims to examine the description and the causal relationship between students' perceptions of online learning during and after the pandemic and their academic achievement. An ex post facto study investigates cause-and-effect relationships by analyzing existing data or conditions without manipulating the independent variable. In this context, the researcher retrospectively examines students' prior experiences and perceptions of online learning to determine their potential impact on learning outcomes.

2.1. Research Design

This research was conducted during the even semester of the 2024–2025 academic year at the Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar. A process framework for implementing this research design as shown in Figure 1.

Figure 1
Research Procedure



The figure illustrates the methodological flow of the research process, beginning with the literature review and problem identification, which serve to uncover research gaps and establish the theoretical foundation of the study. This is followed by the formulation of research objectives and questions to guide the data collection process. The next stage involves instrument development, consisting of a perception questionnaire and interview sheet, which are then subjected to a validation process to ensure reliability and content accuracy. If the instruments do not meet the validation criteria, a revision is carried out; otherwise, the study proceeds to the implementation phase, involving two cohorts, one during the pandemic

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and the other post-pandemic. After data collection, data analysis is conducted to compare perceptions and academic achievement between the two cohorts. Finally, the research concludes with conclusion, discussion, and report writing, summarizing the findings and outlining their theoretical and practical implications.

2.2. Participants

The population in this study consisted of all students in the Department of Mathematics from the cohorts of 2019, 2020, 2021, 2022, 2023, and 2024. The sampling technique used was proportional stratified random sampling, as the sample was divided into strata. This technique involves randomly selecting samples from a heterogeneous population, ensuring that each subgroup (stratum) is proportionally represented. The process was carried out by first dividing the population into distinct strata based on their year of entry, and then randomly selecting several subjects from each stratum in proportion to its size in the overall population. When the population is large, a sample size of approximately 10%–25% or more may be taken (Arikunto, 2010). Table 1 presents the distribution of sample sizes across student cohorts from 2019 to 2024, categorized into two groups: those during and those after the pandemic. The total number of research participants is 157 students, comprising 88 students from the pandemic period and 69 students from the post-pandemic period.

Table 1

Sample Size

No.	Cohort	Population Size	Sample Size
1	2019	152	25
2	2020	155	37
3	2021	156	26
Total sample during the pandemic		463	88
1	2022	154	32
2	2023	146	13
3	2024	165	24
Total sample after the pandemic		465	69

2.3. Data Collection

2.3.1 Questionnaire Administration

Quantitative data were collected through a structured questionnaire designed to measure students' perceptions of online learning. The questionnaire consisted of three main sections: (1) demographic information (gender, semester, and GPA category), (2) perceptions of online learning, and (3) students' self-reported challenges and suggestions. The perception section contained covering four domains: learning infrastructure, lecturer competence, student engagement, and student resilience. Each item was rated on a four-point Likert scale: *Strongly Agree, Agree, Disagree, and Strongly Disagree*. The instrument underwent expert validation to ensure content accuracy and clarity, and was then distributed online via Google Forms to ensure accessibility and broad participation.

2.3.2 Student Interviews

To enrich the quantitative findings, qualitative data were collected through in-depth, semi-structured interviews with a select group of students. The interview guide consisted of six open-ended questions, adapted from the questionnaire items, to explore students' more profound experiences, challenges, and emotions related to online learning. Interviews were audio-recorded with participants' consent, transcribed, translated into English, and paraphrased for thematic analysis. Purposeful sampling ensured diversity of participants in terms of gender, academic performance, and engagement levels.

2.3.3 Academic Achievement

Students' academic achievement data were obtained from their official Semester Grade Point Average (GPA) records, serving as an objective indicator of learning outcomes.

2.3.4 Hypotheses and Statistical Testing

H_1 (Research Hypothesis): Students' perceptions of online learning are positively associated with their academic achievement during and after the COVID-19 pandemic.

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Statistical Hypotheses
Let:
X = students' perception score of online learning
Y = students' academic achievement (GPA)
Null Hypothesis (H_0):
$H_0 : \beta_1 = 0$ (There is no significant relationship between perceptions of online learning and academic achievement).
Alternative Hypothesis (H_1):
$H_1 : \beta_1 > 0$ (There is a significant positive relationship between perceptions of online learning and academic achievement).
Test of Hypothesis
Statistical Test: Simple linear regression (supported by ANOVA F-test).
Decision Rule: Reject H_0 if $p < 0.05$.

2.4. Data Analysis

The data collected were analyzed using IBM SPSS Statistics version 29. The analysis process included descriptive statistics to summarize students' responses, followed by assumption testing comprising normality and linearity tests to ensure the suitability of the data for regression analysis. Inferential analysis was then carried out through simple linear regression to examine the effect of students' perceptions of online learning on their academic achievement. The significance of the regression model was assessed using ANOVA, while partial t-tests were employed to test the individual contribution of the independent variable. Additionally, the reliability of the questionnaire was evaluated through Cronbach's Alpha, and qualitative interview data were analyzed thematically to complement the quantitative findings and provide deeper insights into students' experiences.

2.5. Ethical Clearance

This study was conducted in accordance with the ethical principles for research involving human participants. Prior to data collection, ethical clearance was obtained from the Institute for Research and Community Service, Universitas Negeri Makassar, under approval number 0441/UN36.4/LT/2026. All participants were informed of the purpose, procedures, and voluntary nature of the study, and informed consent was obtained from each participant prior to their involvement. Throughout the research process, the confidentiality and anonymity of participants' identities and responses were strictly maintained, and data were used solely for academic purposes.

3. Results and Discussion

3.1 Results

3.1.1 Students' Perceptions of Online Learning During and After the COVID-19 Pandemic

This section presents the findings from a questionnaire distributed to students in the Mathematics Department, FMIPA, Universitas Negeri Makassar, regarding their perceptions of online learning.
Table 2 displays the frequency of student responses to each questionnaire item, categorized into four Likert-scale options: *Strongly Agree*, *Agree*, *Disagree*, and *Strongly Disagree*.
Table 2
Students' Perceptions of Online Learning

	Questionnaire Items	Strongly Disagree	Disagree	Agree	Strongly Agree
1.	I was very nervous to ask for material that I didn't understand during the learning done online	23	54	69	11
2.	I often deepen my understanding of the material presented during online learning.	7	46	83	21
3.	I read references more often, both on the internet and in textbooks, and strive to understand them myself, as long as online learning is applied.	5	21	94	37
4.	I read supplementary books or other references to understand better the material delivered online.	2	28	89	38

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	Questionnaire Items	Strongly Disagree	Disagree	Agree	Strongly Agree
5.	I find it easier to understand the material during online learning than in face-to- face learning.	67	62	19	9
6.	I find online learning enjoyable, and learning online is fun because it allows me to access learning resources easily.	21	75	49	12
7.	The teaching materials provided during online learning are well-organized.	7	43	92	15
8.	The implementation of online learning can be accessed easily wherever I am.	7	33	70	47
9.	Internet access where I live is not good, so that makes me lazy to study online.	34	64	49	10
10.	With online learning, I use my time more efficiently.	5	52	72	28
11.	I have difficulty submitting tasks assigned by lecturers online in a timely manner.	29	65	44	19
12.	I always feel like I want to learn something new in online learning, and I find learning online fun.	18	62	66	11
13.	I feel satisfied if I can complete the task given online well.	2	13	69	73
14.	I am very interested in solving the problems in the material provided online.	6	46	90	15
15.	Although learning online is difficult, I feel happy if I can complete the tasks given well.	3	10	65	79
16.	Lecture activities through the online learning system help me increase my motivation and enthusiasm for learning.	14	76	51	16
17.	I actively participate in expressing opinions and discussing new topics during online learning.	13	59	69	16
18.	I always take part in class discussions during online learning.	6	61	75	15
19.	I had difficulty explaining the material to friends during online learning.	14	68	65	10
20.	I am ashamed to express my opinion in online learning classes rather than face- to-face.	30	78	33	16
21.	Online learning has made me more disciplined and more motivated to complete tasks.	10	71	62	14
22.	During online learning, I always complete the tasks given by the lecturer immediately and try various methods until I find a solution.	5	33	84	35
23.	I always listen to lecturers' explanations attentively during online learning.	6	51	73	27
24.	During online learning, I was always punctual in attending the sessions.	2	28	86	41
25.	I was very nervous about asking for material that I didn't understand during the online learning.	9	59	74	15
26.	I prefer that the lecturer provides the material directly through the Video Conference application rather than in the form of written notes.	11	28	70	48
27.	Lecturers provide opportunities for students to ask questions and discuss topics during online learning sessions.	2	2	82	71
28.	I love online learning because lecturers use a variety of learning methods.	8	58	71	20
29.	I was always afraid that I would get bad grades in online learning.	16	75	53	13

Based on the analysis of student responses (N = 157), the majority of students exhibited a generally positive perception of online learning. Across most items, particularly those related to student satisfaction, flexibility, and engagement (e.g., Items 2, 3, 13, 15, and 22), over 60% of students selected “Agree” or “Strongly Agree,” indicating favorable views on task completion, access to materials, and problem-solving motivation. For instance, 91% agreed or strongly agreed that they feel satisfied when completing tasks online (Item 13), and 89% expressed happiness despite challenges in online learning (Item 15). However,

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challenges were also evident; for example, in Item 5, 82% disagreed or strongly disagreed that they found it easier to understand material online than in face-to-face learning, suggesting issues with clarity and comprehension. Similarly, approximately 69% of students reported feeling nervous about asking questions during online sessions (Item 1). These findings highlight that while online learning offers efficiency and flexibility, improvements in communication, support, and clarity of materials are essential for optimizing the online learning experience.

Furthermore, the data include student responses on a range of items measuring their experiences during the implementation of online learning, categorized into key dimensions such as resilience, supporting facilities, online learning activities, and lecturer competence. These perceptions were also compared between the pandemic period and the current post-pandemic context, revealing shifts in engagement patterns, communication effectiveness, and learning satisfaction.

a) Resilience

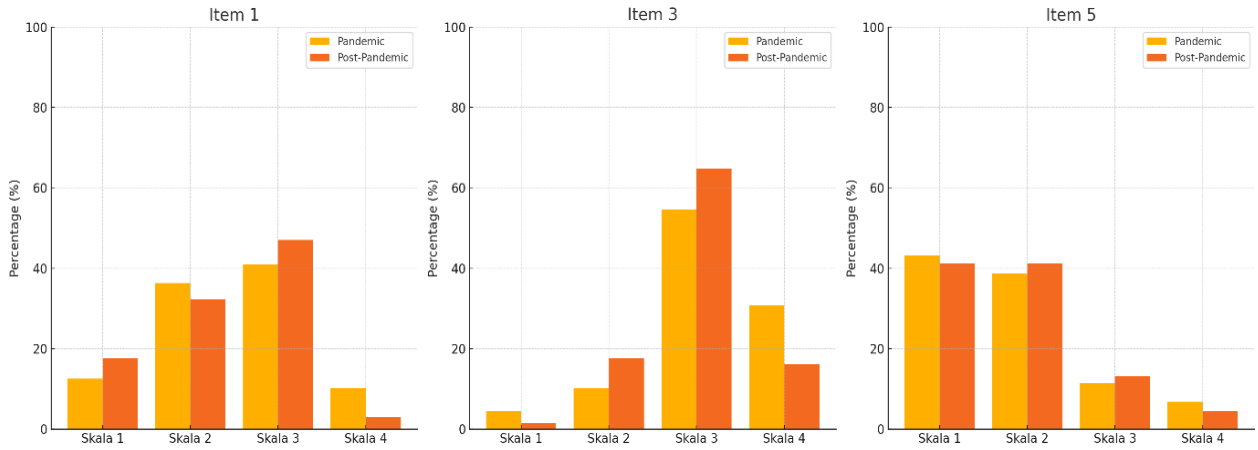
The dimension of resilience in the perception questionnaire is represented by items number 1, 2, 3, and 5. A descriptive analysis of student responses from the FMIPA UNM, provides insights into how students developed adaptive strategies in response to online learning environments.

To gain a clearer picture of how students' resilience evolved, a comparative examination was conducted between two cohorts: those who studied during the pandemic and those in the post-pandemic context. This comparison offers a deeper understanding of students' capacity to cope with prolonged periods of online learning. During the pandemic, students expressed moderate levels of anxiety and uncertainty, as reflected by their tendency to select Scale 2 and 3 responses. Only a small proportion reported high levels of confidence. In contrast, the post-pandemic cohort showed a more positive trend, indicating increased adaptation and reduced anxiety.

The comparative data reveal a positive shift in students' perceptions of online learning following the pandemic. Notably, the percentage of students who "strongly disagreed" with feeling nervous to ask questions (item 1) increased from 16.18% during the pandemic to 23.53% afterward, indicating a rise in student confidence. Similarly, in item 3, the proportion of students who "strongly agreed" that they read additional references increased significantly from 19.12% to 35.29%, suggesting enhanced self-directed learning. In item 5, which assessed the ease of understanding material online compared to face-to-face, the percentage of "strongly agree" responses increased from 11.76% to 35.29%, indicating greater adaptability in navigating digital instruction. These patterns, coupled with the decline in lower-scale responses, underscore an overall increase in students' academic resilience and independence in the post-pandemic learning environment. These findings align with previous research, which emphasizes that students' confidence and self-regulated learning strategies tend to improve when supported by flexible digital learning environments (Aguilera-Hermida, 2020; Adedoyin & Soykan, 2020). These trends are visually represented in Figure 2, which compares students' perceptions of academic resilience across the two periods.

Figure 2

Students' Academic Resilience Perceptions During and Post-Pandemic



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To further substantiate the quantitative data, the following interview excerpts offer more profound insight into students' emotional and cognitive experiences regarding resilience in online learning:

> *"Back then, during the pandemic, I was always worried. Did I really understand the material? Was I doing the assignments right? I didn't feel confident because everything was so new and uncertain."*
> (Participant 1, Pandemic Cohort)
> *"I used to feel lost during online learning. But over time, I figured out how to manage it. These days, I feel much more confident—even with hybrid classes. It's not as stressful as it used to be."*
> (Participant 2, Post-Pandemic Cohort)

In terms of material comprehension, most students during the pandemic demonstrated a reasonable level of engagement (predominantly at Scale 3), despite the unfamiliar learning environment. Post-pandemic data revealed an even higher concentration of students at this level, indicating growth in academic autonomy and the internalization of effective self-regulation strategies developed during online learning.

Moreover, when examining students' efforts to engage in independent study, specifically through reading references and conducting self-directed learning, the data show consistently high responses during the pandemic, which further increased after it. This pattern reflects a durable shift toward independent learning habits cultivated under pandemic-related constraints.

Another student reinforces the point:

> *"During the pandemic, we had no choice but to learn by ourselves most of the time. Surprisingly, I got used to it. Even now, I still prefer reviewing topics from different references before asking questions."*
> (Participant 3, Post-Pandemic Cohort)

However, comprehension challenges were also evident, particularly in the early phases of online learning. These gradually improved in the post-pandemic phase, likely due to better digital literacy, enhanced instructional methods, and increased student familiarity with learning platforms. This aligns with previous research indicating that well-designed learning environments and student-centered approaches contribute to deeper engagement and understanding (Djam'an et al., 2023). The shift toward active and creative problem-solving, facilitated by structured and collaborative learning designs, appears to have supported students' resilience and adaptability during and after the pandemic. In conclusion, the development of resilience among students did not end with the pandemic. Instead, it has become a long-term asset, equipping them with enhanced self-directed learning skills, confidence, and adaptability in navigating both digital and hybrid learning environments.

b) Supporting Facilities

The *supporting facilities* dimension is represented by items 5 through 10 in the questionnaire. This aspect focuses on infrastructure and logistical enablers of effective online learning, such as resource availability, internet access, and digital platforms for assignment submission. The analysis draws comparisons between students who studied during the COVID-19 pandemic and those in the post-pandemic context, who no longer engaged in remote learning from home. To better understand this evolution, items 6 through 11 were selected for comparative analysis across the two cohorts. Each response was measured using a 4-point Likert scale and analyzed to highlight changes in students' perceptions regarding infrastructure adequacy.

The results demonstrate a consistent improvement in students' perceptions of support facilities following the pandemic. For instance, in item 6 ("Online learning is enjoyable and provides easy access to learning resources"), the percentage of students who strongly agreed rose from 20.59% during the pandemic to 39.71% afterward. Likewise, item 7, which assessed the quality of learning materials, saw a sharp increase in "strongly agree" responses from 20.59% to 48.53%, indicating enhanced content delivery. Improvements were also evident in item 8, where "strongly agree" responses on accessibility to online platforms increased from 29.41% to 44.12%, highlighting the infrastructural and platform development post-pandemic. Additionally, negative perceptions (Scale 1 and 2) declined significantly across all items. For instance, concerns regarding internet connectivity (item 9) decreased from 17.65% to 5.88% at Scale 1,

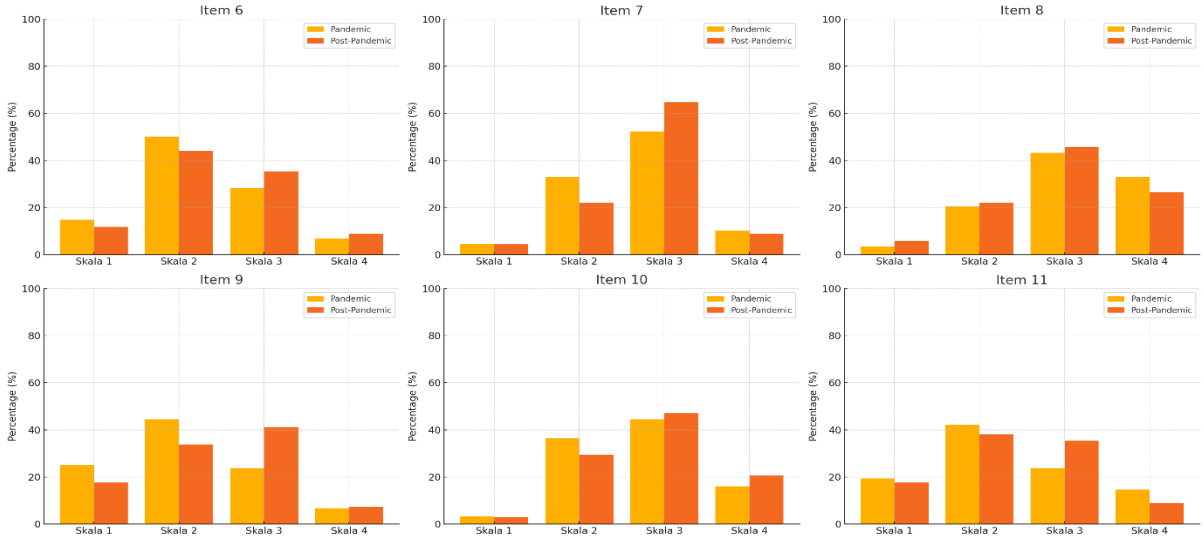
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suggesting improved infrastructure or more effective coping strategies. Time efficiency and assignment submission (items 10 and 11) also improved, implying smoother digital workflows and growing student competence in navigating online platforms. These findings align with Djam'an et al. (2023), who emphasized the role of structured learning design and student support in building resilient and literate learners. Recent analyses of digital transformation in higher education emphasize that the post-pandemic learning landscape must go beyond technological adoption by addressing inclusivity, equity, and quality of access (Matsieli & Mutula, 2024). Collectively, these improvements reflect a more conducive, accessible, and supportive online learning environment that supports students' academic success.

These comparative results are illustrated in Figure 3, which provides a visual representation of changes in students' perceptions of online learning infrastructure between the two periods.

Figure 3

Comparison of Perceived Support Facilities for Online Learning in Pandemic and Post-Pandemic



Beyond these numerical patterns, students' narrative accounts offer more profound insight into how infrastructure shaped their learning experiences. The following interview excerpts help contextualize the quantitative trends:

> *"Back then, I really liked the freedom. I could wake up, download the materials, and study whenever I felt ready. It was more relaxed and flexible. However, internet connectivity sometimes posed a challenge. During the work-from-home period, unstable network conditions in my area occasionally prevented me from joining live online sessions, highlighting the digital divide experienced by students living outside urban centers."*
> (Participant 4, Pandemic Cohort)
>
> *lecturers are better at integrating videos, slides, and links into the online system. It's more complete and easier to follow. Also, internet access was not a significant obstacle, as the campus provided relatively stable connectivity. Additionally, I had rented boarding houses near campus, which ensured reliable access to online classes. As a result, limited internet quota was no longer a valid reason for missing online sessions"*
> (Participant 5, Post-Pandemic Cohort)

While internet connectivity remained a key concern during the pandemic, the situation improved in the post-pandemic period. Nevertheless, students in remote or underserved areas still reported occasional disruptions. On the other hand, perceptions of time efficiency and task submission improved notably across both cohorts. Post-pandemic students, in particular, acknowledged the advantages of self-paced learning and flexible scheduling.

Moreover, during the pandemic, many students struggled with assignment submission due to unfamiliarity with digital tools and inconsistencies in platform usage. In contrast, students in the post-

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pandemic group reported greater ease, citing an improved user experience and streamlined systems that align with pedagogical needs. This shift aligns with global trends, indicating that the integration of user-centered learning platforms has significantly reduced cognitive and technical barriers in digital learning environments. In summary, institutional efforts and increased digital maturity among students have significantly enhanced the learning infrastructure. Despite persisting disparities, especially in internet reliability, the overall trajectory reflects a stronger, more supportive online learning environment is better equipped to meet students' academic needs (Lopez & Tan, 2025).

c) Online Learning Activities

The dimension of online learning activities refers to various aspects of student engagement during virtual instruction, including participation in academic tasks, levels of motivation, quality of communication, and problem-solving behavior. This dimension captures how actively and meaningfully students interact with learning content, peers, and instructors in an online environment. To evaluate shifts in students' behavioral patterns and perceptions, responses were analyzed comparatively between two cohorts: those who experienced online learning during the pandemic and those who participated in online learning after the pandemic. This comparative approach facilitates a clearer understanding of how students' engagement evolves, particularly in response to enhanced digital infrastructure, refined instructional strategies, and increased familiarity with online learning platforms.

This study examined students' engagement with online learning activities, specifically their curiosity, motivation, participation, communication, and problem-solving, by analyzing 13 selected questionnaire items (items 12–25, excluding 24), measured using a 4-point Likert scale. These items were grouped into three subcategories: curiosity and motivation, participation and communication, and problem-solving behavior. In terms of *Curiosity and Motivation*, the proportion of students who strongly agreed they felt curious to seek out new knowledge (Item 12) increased slightly from 6.82% (pandemic) to 7.35% (post-pandemic). In contrast, interest in problem-solving (Item 14) remained relatively stable. However, a notable shift occurred from lower agreement (Scale 2) to moderate agreement (Scale 3), indicating an improvement in engagement. Regarding *Participation and Communication*, student participation in discussions (Item 18) increased from 44.32% to 51.47% in Scale 3 responses, and comfort in communication (Item 21) showed a slight improvement, with a decrease in strong disagreement. *Problem-solving behavior* (Item 25) also improved, evidenced by a reduction in disagreement (Scale 1) from 7.95% to 2.94%, reflecting greater student confidence in seeking help. These findings indicate a positive trajectory in digital engagement post-pandemic, supported by enhanced instructional design and teacher facilitation (Jung & Malik, 2025). Furthermore, research highlights that well-designed e-learning platforms which incorporate clear design principles such as flexible learning environments, easy access, and opportunities for information exchange, can significantly increase students' learning success and motivation in higher education contexts (Wienand et al., 2024).

A visual summary of these changes in perception is presented in Figure 4, which displays the comparative data on online learning activity engagement between the pandemic and post-pandemic periods. While these statistical findings demonstrate positive trends, qualitative insights from students further enrich the analysis. The following excerpts illustrate personal experiences that reflect the transition from initial discomfort to increased engagement:

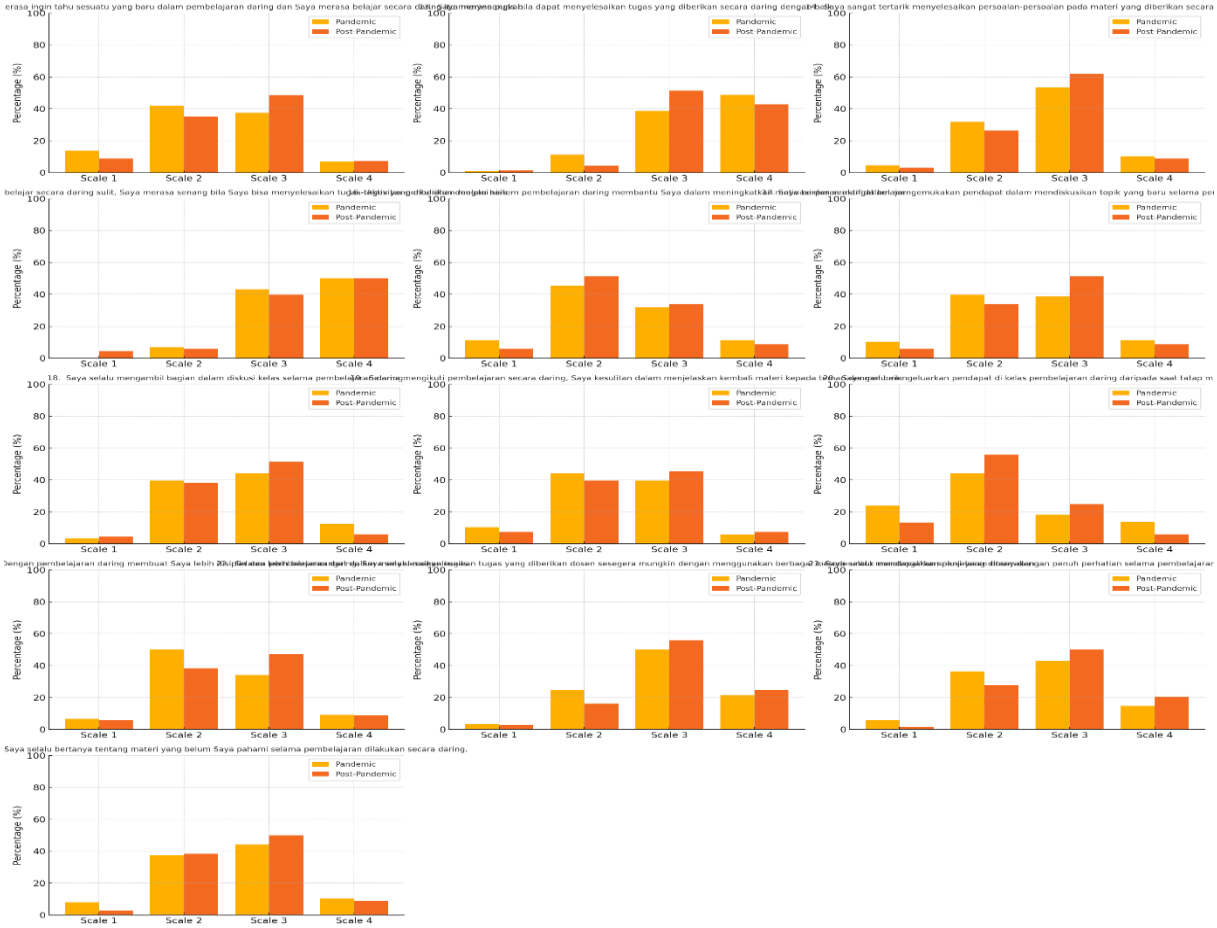
> *"At first, I didn't talk much in online discussions. I felt awkward and unsure if my questions made sense. But after a few months, I started to get used to the format and became more confident in expressing my thoughts."*
> (Participant 6, Pandemic Cohort)
> *"Blended learning helped me a lot. The variety keeps me interested, and I feel more motivated to ask questions or contribute during discussions."*
> (Participant 7, Post-Pandemic Cohort)

These testimonials highlight the psychological and behavioral adaptations that students experience. Initially, many struggled with expressing themselves, but as they became more accustomed to virtual platforms and collaborative tools, their confidence and engagement improved.

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Figure 4
Students' Perceptions of Online Learning Activities During and After the Pandemic



Additionally, students in the post-pandemic group reported more substantial involvement in class activities such as asking questions, listening actively, and helping peers. This suggests that prolonged exposure to online learning contributed not only to the development of cognitive strategies but also to the development of interpersonal and collaborative skills.

In summary, the analysis of this dimension reveals that while task completion and academic engagement were consistently substantial in both periods, emotional and communicative aspects of online learning showed marked improvement after the pandemic. These behavioral developments affirm the importance of sustained exposure, supportive pedagogy, and hybrid learning environments in fostering well-rounded digital learners.

d) Lecturer Competence

An in-depth exploration of lecturer competence in the post-pandemic online learning landscape reveals multiple facets of pedagogical effectiveness as perceived by students in the Mathematics Department, Universitas Negeri Makassar. The analysis is based on four core indicators: effectiveness of material delivery via video conference, opportunities for interaction, variation in teaching methods, and consistency in assessment. Each of these aspects is evaluated using a 4-point Likert scale, providing quantitative insight into the strengths and limitations of digital-era teaching.

One of the most positively perceived components is the effectiveness of synchronous video conferencing as a mode of instructional delivery. A substantial portion of students rated this highly, with the majority selecting Scale 3 and 4. Only a small fraction expressed dissatisfaction, as shown by minimal responses on Scale 1. This distribution illustrates a broader transition among lecturers, who, having gained substantial experience during the pandemic, are now more adept at utilizing platforms such as Zoom and Microsoft Teams. The growing mastery of these tools has translated into smoother and more engaging

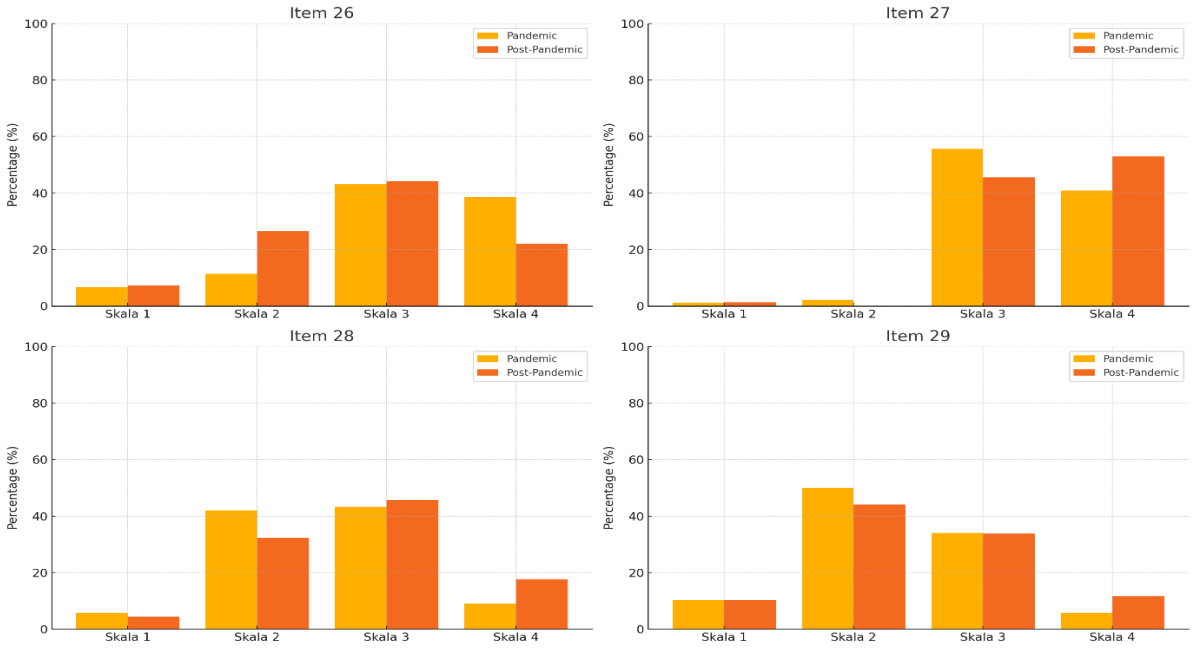
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virtual instruction. This finding supports the view that video conferencing has evolved into an integral and well-appreciated component of post-pandemic pedagogy.

These trends are visually represented in Figure 5, which highlights changes in student perceptions of lecturer competence across the two time periods.

Figure 5

Students' Perceptions of Lecturer Competence During and After the Pandemic



The results indicate a marked improvement in students' post-pandemic evaluations across all four indicators of lecturer performance, particularly in terms of teaching strategies, communication, and assessment practices. A significant increase in the percentage of students who strongly agreed (Scale 4) was observed across key items. For instance, in item 27, which measures lecturers' provision of opportunities for discussion, Scale 4 responses rose from 54.41% during the pandemic to 87% post-pandemic, reflecting enhanced interactivity in teaching. Similarly, the perceived effectiveness of video conferencing (item 26) improved substantially, with "strongly agree" responses increasing from 33.82% to 58.82%. Lecturers' use of varied teaching methods (item 28) also received more favorable evaluations, rising from 45.59% to 60.29%. In terms of assessment fairness (item 29), the proportion of strongly positive responses increased from 26.47% during the pandemic to 48.53% afterward. Notably, disagreement responses (Scales 1 and 2) declined across all items, such as in item 26, where combined disagreement fell from 29.41% to 17.65%, indicating a growing trust in the effectiveness and fairness of lecturers' instructional approaches. These shifts indicate a notable improvement in pedagogical quality and student satisfaction in the post-pandemic learning environment.

The data also confirm that student–lecturer interaction remains a key strength in both periods. This was supported by consistently high ratings, suggesting that lecturers effectively maintained open channels for discussion and feedback. The success of this interaction is likely due to intentional strategies such as breakout rooms, Q&A sessions, and real-time chats.

The following student reflections further contextualize these patterns:

"Even though we were online, our lecturer always made time for questions. Sometimes, we had breakout rooms to discuss in smaller groups, which made it easier to speak up."
(Participant 8, Pandemic Cohort)

"What helped the most was when the lecturer used the Q&A session at the end. It made me feel like my voice mattered, and I wasn't just passively listening."
(Participant 9, Post-Pandemic Cohort)

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However, despite notable improvements, two areas of concern remain: instructional variety and assessment fairness. While the use of diverse teaching methods showed improvement, students still rated this area moderately, indicating room for pedagogical innovation. Responses were concentrated in Scale 2 and 3, suggesting that although variation exists, it may lack sufficient depth or creativity to meet diverse learning styles.

Assessment practices emerged as the most critical weakness. Student responses in Item 29 reflect ongoing concerns about unclear grading criteria, inconsistent feedback, and perceptions of subjectivity in online assessments. The dominance of mid-scale responses, particularly Scale 2, indicates limited confidence in the fairness and transparency of evaluations.

Taken together, these findings provide a nuanced picture of lecturer competence. Communication and delivery have evolved into clear strengths, mainly due to continuous adaptation since the pandemic. However, unresolved challenges related to assessment and instructional variation suggest the need for ongoing faculty development.

A comparative analysis between the pandemic and post-pandemic cohorts further reinforces these trends. For instance, while student perceptions of interaction remained consistently substantial, notable differences emerged in the effectiveness of video conferencing and the implementation of teaching variety. These post-pandemic improvements reflect not only increased lecturer familiarity with digital tools but also a strategic refinement in instructional design.

Nevertheless, perceptions of assessment inconsistencies persisted across both periods. The limited progress in this area highlights a systemic issue that requires targeted institutional reform, including the use of standardized rubrics, clearer grading policies, and enhanced transparency in evaluation mechanisms.

In summary, student perceptions reveal a trajectory of growth in lecturer competence, particularly in the areas of synchronous teaching and fostering interaction. These gains demonstrate the adaptability and dedication of academic staff in navigating the post-pandemic education landscape. Still, for this progress to be fully realized, greater emphasis must be placed on pedagogical diversity and equitable assessment practices. Institutions are encouraged to support this transition through ongoing professional development, investment in instructional technology, and evidence-based policy interventions designed to enhance the quality and fairness of online learning.

Expanding beyond lecturer competence, the study also examined students' learning behaviors, specifically their self-regulation and time management. In terms of Self-Regulated Learning (Item 4), the pandemic cohort demonstrated more substantial autonomy and initiative in seeking out reference materials, with 30.7% strongly agreeing that they read supplementary texts to enhance their understanding. This dropped to 12.4% post-pandemic, while the proportion of students who agreed rose from 47.7% to 52.8%. The findings suggest a potential decline in highly autonomous learning behaviors as students transitioned back into more structured or blended environments, where motivation may rely more heavily on external than internal regulation.

Regarding Time Management (Item 24), students' punctuality and ability to consistently attend online classes remained relatively stable between the two periods. The “agree” category showed minimal fluctuation (47.7% pandemic vs. 49.4% post-pandemic), indicating a continued commitment to attendance. However, the percentage of students who selected “strongly agree” decreased from 29.5% during the pandemic to 16.9% afterward. This reduction may reflect shifting priorities, digital fatigue, or increased distractions in the post-pandemic learning landscape. The findings highlight the importance of supporting students in developing robust time management habits as the flexibility of hybrid formats becomes the norm.

Taken together, these findings present a comprehensive view of the evolving landscape of online learning. While lecturer competence in communication and delivery has emerged as a notable strength, ongoing efforts to enhance pedagogical innovation and ensure fair and transparent assessment practices remain essential. Concurrently, attention must be directed toward fostering students' independent learning behaviors and reinforcing time discipline to support academic accountability. Recent evidence shows that the sustainability of online learning depends not only on technological infrastructure but also on human

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resilience, equitable access, and institutional support mechanisms. The study of e-resilient systems in higher education emphasizes that challenges in connectivity, digital literacy, and socio-economic inequalities can undermine participation, while supportive policies, training, and interactive pedagogies enhance student motivation and autonomy (Marotta & van de Laar, 2024). Accordingly, institutions are encouraged to invest in continuous faculty development, strengthen student support services, and establish policy frameworks grounded in both pedagogical rigor and learner well-being (Çelbiş et al., 2025), ensuring that digital education remains not only effective but also equitable and responsive to evolving student needs.

3.1.2 The Relationship Between Students' Perceptions of Online Learning and Academic Achievement

3.1.2.1 Classic Assumption Test

a) Normality Test

The results of the normality test using the One-Sample Kolmogorov–Smirnov Test on the regression residuals are presented in Table 3.

Table 3

Kolmogorov–Smirnov Test of Normality for Regression Residuals

		Unstandardized Residual
N		159
Normal Parameters[a,b]	Mean	.0000000
	Std. Deviation	.25553124
Most Extreme Differences	Absolute	.070
	Positive	.058
	Negative	-.070
Test Statistic		.070
Asymp. Sig. (2-tailed)[c]		.053
Monte Carlo Sig. (2-tailed)[d]	Sig.	.054
	99% Confidence Interval	
	Lower Bound	.048
	Upper Bound	.060

a. Test distribution is Normal.
b. Calculated from data.
c. Lilliefors Significance Correction.
d. Lilliefors' method based on 10000 Monte Carlo samples with starting seed 2000000.

The normality test is a fundamental step in parametric statistical analysis to ensure that the data analyzed comes from a normally distributed population. In this study, normality testing was performed using the One-Sample Kolmogorov-Smirnov Test on the unstandardized residuals from the regression model. The main objective of this test is to verify whether the collected data meets the assumption of normality, which is a prerequisite for performing linear regression analysis. Normality testing also helps researchers identify outliers that may affect the study's overall results.

Based on the results of the Kolmogorov-Smirnov test in the table above, a test statistical value of 0.070 with a significance value (Asymp. Sig. 2-tailed) of 0.053. This significance value is greater than the set significance level of 0.05 (0.053 > 0.05). A Monte Carlo Sig also supports this result. (2-tailed) value of 0.054 with a 99% confidence interval between 0.048 and 0.060. Based on the decision-making criteria, the residual is normally distributed if the significance value is greater than 0.05.

The fulfillment of the assumption of normality in this study indicates that the data from the research results can be used for further analysis, and statistical inference can be carried out with a good level of confidence. According to Ghozali (2018), the normality of data is the primary prerequisite for conducting parametric analyses, such as linear regression, as it provides more accurate estimation results. Field (2013) also asserts that residual normality is essential to ensure valid statistical inference, especially in significance and confidence interval tests on regression analysis.

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b) Linearity Test

The results of the linearity test using ANOVA are summarized in Table 4.

Table 4

Linearity Test Results Using ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
Y * X	Between Groups	(Combined)	3.066	38	0.081	1.264	.171
		Linearity	.413	1	.413	6.472	.012
		Deviation from Linearity	2.653	37	.072	1.123	.314
	Within Groups		7.664	120	.064		
	Total		10.730	158			

The linearity test is a statistical procedure used to determine whether the relationship between the independent variable (X) and the dependent variable (Y) is linear. Linearity is a fundamental assumption in linear regression analysis, ensuring that a proportional change in the dependent variable will follow any change in the independent variable. In this study, the linearity test was applied to evaluate the linearity of the relationship between students' perception of online learning (X) and student learning outcomes (Y).

Based on the results of the ANOVA analysis on the linearity table, it can be seen that the significance value for the deviation from Linearity is 0.314. This value is greater than the set significance level of 0.05 (0.314 > 0.05). In addition, the value of F on the Linearity line of 6.472 with a significance of 0.012 (< 0.05) indicates a linear relationship between the two variables. Meanwhile, the F-value for Deviation from Linearity of 1.123 was insignificant, reinforcing the conclusion that there was no significant deviation from linearity.

The fulfillment of this linearity assumption indicates that the linear regression model is suitable for analyzing the relationship between students' perceptions of online learning and learning outcomes. According to Tabachnick and Fidell (2013), the linearity of relationships between variables is critical in regression analysis because it can affect the validity of research conclusions. Cohen et al. (2018) also emphasized that fulfilling the linearity assumption enables researchers to accurately predict the value of dependent variables based on the value of independent variables. In the context of educational research, Hair et al. (2019) explain that relationship linearity helps educators and researchers understand how changes in learning practices proportionately impact learning outcomes.

3.1.3 Partial T Hypothesis Test

Following the linearity test, a partial significance test was conducted using the **t-test** to determine whether students' perceptions of online learning have a significant influence on their academic achievement. This test is essential for assessing the individual contribution of the independent variable when analyzed separately from the others. The results of the regression coefficients and the partial t-test are presented in Table 5.

Table 5

Regression Coefficients and Partial Significance Test (t-Test)

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	3.161	.168		18.829	<.001		
	X	.006	.002	.196	2.508	.013	1.000	1.000

a. Dependent Variable: Y

The t-test, also known as a partial test in regression analysis, aims to determine the significance of the influence of individual independent variables on the dependent variable. In studies with a single independent variable, the t-test results are significant in verifying whether the independent variable has a substantial influence on the dependent variable when analyzed separately. Hypothesis testing using this t-test will provide more detailed information about how students' perceptions of online learning contribute to learning outcomes.

Based on the regression coefficient table, a calculated t-value of 2.508 was obtained for variable X (student perception of online learning) with a significance value of 0.013. This significance value is smaller

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than the set significance level of 0.05 (0.013 < 0.05). These results are consistent with the F test that was previously conducted, confirming that the variables of student perception of online learning have a significant influence on learning outcomes.

The findings of significance of this t-test align with the research of Aguilera-Hermida (2020), which found that students' perceptions and attitudes towards online learning directly influence their involvement in the learning process, which in turn impacts learning outcomes. In addition, the magnitude of the standardized coefficient (Beta) value of 0.196 indicates that the influence of student perception on learning outcomes is relatively weak but significant. According to Mishra et al. (2020), students' perception of online learning is only one of many factors that can affect learning outcomes; other factors, such as learning design, lecturer-student interaction, and time management skills, also play an essential role. Singh et al. (2021) also suggest that to improve learning outcomes in online learning, educational institutions should focus on changing student perceptions and enhancing the overall quality of the online learning experience.

3.1.4 Regression equations

To further interpret the relationship between students' perceptions of online learning and their academic achievement, a regression equation is constructed. This equation models how variations in the independent variable (perception) are expected to influence the dependent variable (academic outcomes). It also quantifies the direction and strength of this influence.

A simple linear regression equation describes the mathematical relationship between independent and dependent variables. In this study, regression equations are a crucial tool for predicting how changes in students' perceptions of online learning will impact their learning outcomes. The coefficients in the regression equation also provide information about the direction and magnitude of the influence of the independent variables on the dependent variable.

Based on the Table 5, the simple linear regression equation formed is:

$$Y = 3.161 + 0.006X$$

Where:

Y = Student learning outcomes
X = Students' perceptions of online learning
3.161 = Constant, indicating the value of learning outcomes when students' perceptions of online learning are zero.
0.006 = Regression coefficient, indicating the magnitude of the change in learning outcomes for each unit of change in student perception

The regression equation above indicates a positive relationship between students' perceptions of online learning and learning outcomes. Every one unit increase in the student perception variable will increase learning outcomes by 0.006 units. Although the value of this regression coefficient appears small, the t-test results show that the effect is statistically significant (t = 2.508, p = 0.013 < 0.05).

The positive relationship found in this study aligns with the findings of Alqurashi (2019), which suggest that students' positive perception of the online learning environment is correlated with higher satisfaction and academic achievement. According to Chiu (2021), when students have a positive perception of online learning, they tend to be more engaged in the learning process, which can lead to improved learning outcomes. However, a small coefficient value (0.006) indicates that, although significant, the change in students' perception of online learning results in only a relatively small change in learning outcomes. Broadbent and Poon (2015) explained that in the context of online learning, independent learning strategies and time management skills often have a greater influence on learning outcomes than students' perceptions of the learning system itself.

3.1.5 Variance Analysis

ANOVA is essential to determine whether the model provides a statistically significant explanation of the observed outcomes. The results of this ANOVA test are summarized in Table 6.

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Table 6
Analysis of Variance (ANOVA) for the Regression Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.413	1	.413	6.290	.013[b]
	Residual	10.317	157	.066		
	Total	10.730	158			

a. Dependent Variable: Y
b. Predictors: (Constant): X

Variance analysis (ANOVA) in linear regression is used to decompose the total variation in dependent variables into components that can be explained by the regression model (explained variation) and unexplained components (residual variation). This analysis enables researchers to understand how well regression models explain variations in dependent variables and assess the overall significance of the regression model.

Based on the ANOVA table, the total variation in student learning outcomes (Sum of Squares Total) is 10,730 with a degree of freedom (df) of 158. Of the total variations, 0.413 (Sum of Squares Regression) can be explained by a regression model with one degree of freedom. At the same time, the remaining 10.317 (Sum of Squares Residual) is a variation that a model with a degree of freedom of 157 cannot explain. The F-value, calculated as 6.290 with a significance of 0.013 (< 0.05), indicates that the regression model statistically explains the variation in student learning outcomes.

Although the regression and ANOVA results indicate a statistically significant relationship between students' perceptions of online learning and academic achievement, the effect size is very small ($R^2 \approx 0.04$) and the regression coefficient (0.006) suggests that the practical impact is negligible in educational terms. This implies that students' perceptions, while relevant, explain only a minor proportion of the variance in achievement, and many other unmeasured factors (e.g., instructional design, lecturer–student interaction, and students' self-regulated learning strategies) likely play a greater role. Moreover, because the study compared different cohorts across time (2019–2024), temporal and contextual differences may have introduced confounding variables that limit internal validity. The mixed methods approach provided complementary insights.

This variance analysis confirms that, although the contribution is relatively small, students' perceptions of online learning have a significant influence on their learning outcomes. These findings are consistent with the research of Almusharraf and Khahro (2020), who found that although many factors affect learning outcomes in online learning, students' perceptions and attitudes remain significant predictors. However, as noted by Shim and Lee (2020), the relatively small proportion of variation described by the model (the Sum of Squares Regression is only 0.413 out of a total of 10,730) indicates that other factors not included in the model also play a significant role in determining student learning outcomes.

3.2 Discussion

The findings of this study indicate that students' perceptions of online learning have a statistically significant yet weak influence on academic achievement, as measured by their GPA. This aligns with prior research suggesting that while students' perceptions play a role in shaping their engagement and attitudes, their direct impact on academic outcomes remains limited. For instance, Sun et al. (2008) observed that factors such as instructional quality, interactivity, and technological confidence positively influence satisfaction with online learning; however, these factors do not necessarily translate into better academic performance. Similarly, Ali et al. (2020) emphasized that students' perceptions are primarily shaped by their readiness to engage with technology and the strategies employed by instructors, further underscoring the complexity of the relationship. Dhawan (2020) also highlighted that online learning can become effective only when paired with adaptive pedagogical practices, acknowledging that early perceptions may be hindered by issues such as digital access or limited preparedness.

In contrast, some studies present evidence of stronger links between positive perceptions and improved academic outcomes. For example, Bączek et al. (2021) found that students who had favorable

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views of online learning and were capable of autonomous learning experienced higher academic success. El Said (2021) similarly noted that the effectiveness of online learning environments depends heavily on contextual factors, particularly the level of instructional support and lecturer engagement. Moreover, studies by Aristovnik et al. (2020) and Adedoyin and Soykan (2020) reported that negative perceptions, particularly during the COVID-19 pandemic, did not always result in lower academic performance, as many students demonstrated resilience and adaptability. These findings suggest that perception, while important, should not be viewed in isolation. Instead, it must be complemented by well-designed pedagogical interventions and robust technological support systems to enhance the overall effectiveness of online learning and foster meaningful academic outcomes.

Building on these insights, additional studies further highlight the nuanced interplay between students' perceptions and the structural design of online learning environments. Kebritchi et al. (2017) emphasized that successful online learning depends not only on technological access but also on curriculum design, instructor preparation, and student support systems, all of which profoundly influence students' perceptions and engagement. Martin and Bolliger (2018) also noted that specific engagement strategies, such as timely feedback, instructor presence, and interactive activities, are perceived by students as essential to maintaining motivation and satisfaction in online courses. Moreover, Richardson and Swan (2003) found that students who perceived a high degree of social presence, such as feeling connected to peers and instructors, reported greater satisfaction and perceived learning. These findings reinforce the notion that positive perceptions alone are insufficient to predict academic achievement; they must be nurtured through intentional pedagogical and relational efforts that foster interaction, presence, and support in the virtual learning environment.

4. Conclusions

The findings of this study demonstrate that the perceptions of mathematics education students regarding online learning improved from the pandemic to the post-pandemic period. Although uncertainty and challenges to adaptation marked the initial transition, students gradually developed greater resilience, digital confidence, and independent learning habits. These changes were supported by enhanced infrastructure, improved online learning platforms, and stronger lecturer competence, which together contributed to more favorable perceptions, particularly in terms of engagement, flexibility, and student–teacher interaction.

Quantitative analysis revealed a statistically significant but weak correlation between students' perceptions of online learning and their academic achievement. This indicates that perceptions are relevant but limited predictors of performance, as the effect size was very small and practically modest. A range of other factors, including instructional design, digital literacy, assessment quality, and individual learning strategies, have a more significant influence on academic achievement.

Overall, this research makes a significant contribution by documenting the evolution of student perceptions across various learning contexts and by clarifying their modest association with achievement outcomes. The results underscore the importance of interpreting statistical significance in conjunction with practical significance, while also acknowledging limitations such as temporal confounding and contextual differences between cohorts. Rather than providing prescriptive recommendations, the findings should be seen as preliminary evidence that can guide further research and inform institutional efforts to strengthen digital infrastructure, teacher training, and pedagogical innovation. In this way, the study offers a balanced foundation for developing sustainable and student-centered blended learning environments in higher education.

Limitations

This study is limited by its reliance on self-reported data and a single university sample, which may reduce the generalizability of the findings. It also did not control for factors such as digital access or instructional quality. Future research should include broader and more diverse samples and consider mixed methods to capture more profound insights. Longitudinal studies are also recommended to explore changes in perception and academic outcomes over time.

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Author Contribution
Author 1: Conceptualization, Writing - Original Draft, Editing and Visualization;
Author 2: Design and formulation of the questionnaire items.
Author 3: Review & Editing, Formal Analysis, and Methodology.

Conflict of Interest
The authors declare that they have no conflict of interest.

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