

Exploring the Influence of Banach Space Complexity and Abstraction on Students' Attitude toward Learning Higher-Level Mathematics

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ARTICLE INFORMATION	ABSTRACT
Article history: Published: October 2026 Keywords: Banach Spaces Functional Analysis Abstract Nature Normed Function Space Mathematical Confidence	This study investigates the effect of Banach space complexity and abstraction on university students' attitudes toward learning higher-level's mathematics. Banach space is among some central concepts in functional analysis, it is mainly known for its theoretical depth and abstract nature, which can cause significant cognitive and emotional challenges for learners. Four null hypotheses guided the study and a research surveyed approach on mathematics graduates were used through a structured close-ended Banach Space Students Attitude Questionnaire, to assess the respondents' perceptions, motivation, anxiety, and engagement related to Banach space theory. One hundred mathematics and mathematics education members of National Youth Service Corps in two local government areas of Lagos State, Nigeria were used. Data collected were analyzed to test the null hypotheses; the analysis rejected all the four null hypotheses. The findings revealed that students perceived Banach spaces as more difficult than other mathematical topics, and this perception causes poor motivation, increased anxiety, and lower confidence. This study concludes that abstraction in higher-level mathematics negatively influence learning attitudes and recommends that mathematics lecturers should introduce Banach spaces through familiar spaces before progressing to more advanced examples of normed function spaces, and they should build mathematical confidence progressively in students by breaking complex proofs into smaller steps and providing constructive feedback to class.

1. Introduction

Higher-level pure mathematics is typified by its theoretical depth, abstract reasoning, and reliance on symbolic logic. Among its most challenging scopes is functional analysis, where Banach spaces—play a foundational role. Despite the good quality of functional analysis, Asada, Fukawa-Connelly & Weber (2024) found that students often struggle with the abstraction and complexity of some functional analysis topics, which cause negative influence on their confidence, motivation, and overall attitude toward learning. Banach spaces, introduced by Stefan Banach, are essential in understanding convergence, continuity, and boundedness in infinite-dimensional spaces. Their abstract nature, however, presents a cognitive challenge for students transitioning from concrete to theoretical mathematics.

Moore et al (2024) emphasizes the difficulty which students face when moving from operational to structural understanding, while Asada, Fukawa-Connelly & Weber (2024) highlights the psychological shift required to grasp abstract mathematical objects. Aquilina, Di Martino & Lisarelli (2025) found that negative emotions such as anxiety and frustration often accompany the study of abstract topics, affecting students' engagement and persistence.

Although some studies advocate for contextualizing abstract mathematics through applications, few have focused specifically on Banach space theory. This study investigates how the perceived difficulty and abstraction of Banach space has impact on undergraduate students' attitudes toward learning higher-level mathematics. By examining engagement levels, emotional responses, and performance outcomes, the research aims to uncover barriers to logical and successful learning and propose strategies for improving instruction in advanced mathematical topics.

1.1 Research Questions

- How do students perceive the complexity and abstraction of Banach space theory in higher-level mathematics?
- What is the relationship between students' attitudes toward Banach space theory and their motivation to learn advanced mathematics?
- Does the perceived difficulty of Banach space theory influence students' confidence and engagement in functional analysis?
- Are there significant differences in attitudes toward learning higher-level mathematics between students with high and low perceived understanding of Banach spaces?

1.2 Null Hypothesis

The following null hypotheses would be tested at significant level of 0.05:

- H₀₁: Students do not perceive Banach space theory as more abstract or complex than other higher-level mathematics' topics.
 H₀₂: There is no significant relationship between students' attitudes toward Banach space theory and their motivation to learn advanced mathematics.

H₀₃: The perceived difficulty of Banach space theory does not significantly affect students' confidence or engagement in functional analysis.
 H₀₄: There is no significant difference in attitudes toward learning higher-level mathematics between students with high and low perceived understanding of Banach spaces.

2. Literature Review

Researches on undergraduate proof-based mathematics recognizes that higher mathematics courses involve a substantial change in the nature of mathematical activity, with formal definitions, abstract properties, and proof becoming central to learning (Melhuish et al., 2022). Higher mathematics' courses create learning difficulties when students cannot connect formal definitions with familiar examples or when they lack the prerequisite knowledge required to interpret abstract statements (Murphy, 2016). Tall and Vinner (1981), distinguished between the formal definition of a mathematical concept and the cognitive associations which an individual develops around that concept. They clarified that a student's concept image may be incomplete or inconsistent with the formal mathematical definition.

Aquilina, Di Martino, and Lisarelli's systematic literature review examined 180 studies published between 2016 and 2023 on mathematics learning. Their review found continuing concerns about how attitudes toward mathematics are defined, theoretically explained, and measured. This emphasized the multidimensional nature of the construct and the need for greater consistency between research questions, theoretical frameworks, and measurement instruments (Aquilina, Di Martino & Lisarelli, 2025).

Bandura's (1997) self-efficacy theory concerns individuals' beliefs about their capabilities to organize and execute the actions required to achieve particular outcomes. In mathematics education, mathematical self-efficacy refers to students' confidence in their ability to understand concepts, solve problems, and perform mathematical tasks (Onasanya & Areelu, 2024). Moore et al (2024) affirmed that students studying Banach spaces use to experience differences in self-efficacy even when they encounter similar content.

Laden (2018) on affect in mathematics education emphasizes the role of emotions, beliefs, attitudes, and perceived competence in mathematical learning. McLeod (1992) discussed the significance of beliefs, attitudes, and emotions in understanding students' mathematical experiences, while Di Martino and Zan (2010) developed a multidimensional perspective on students' relationships with mathematics. Stylianides, Stylianides & Moutsios-Rentizos (2024) found that affective perspectives are especially relevant when students encounter abstract mathematics because their reactions may involve more than a lack of conceptual understanding. Some students feel anxious when asked to construct a proof, become frustrated when a definition appears unfamiliar, or lose interest when they cannot find the relevance of a mathematical result (Biehler, Durand-Guerrier & Trigueros, 2024).

Häsä, Westlin, and Rämö (2023) investigated undergraduate mathematics students' attitudes toward mathematical proving in an introductory proof course and found that prior mathematical performance was associated with students' initial self-efficacy, anxiety, and motivation. They concluded that students' self-efficacy increased and their anxiety decreased during the course. Initial motivation was associated with performance on the final course project.

Melhuish et al. (2022) synthesized 104 published reports on teaching proof-based undergraduate mathematics and identified evidence of affective and participation benefits associated with student-centered instruction while also highlighting the need for further research into how instructional practices influence student learning.

This review shows that higher-level mathematics differs from many computationally oriented courses in the central role of definitions, proofs, and abstract properties. In Banach space theory, students are expected always to interpret unfamiliar statements, identify relevant assumptions, and connect several previously learned concepts within a single argument.

2.1 Research Gap

The following gaps provide the basis for the present study.

- **Content-Specific Gap:** Onasanya (2020) noted that many studies on students' attitudes toward mathematics frequently examines the subject broadly or focuses on introductory mathematical proof. So, there is a need to investigate students' attitudes in relation to a specific advanced mathematical domain, namely Banach spaces.
- **Conceptual Gap:** Complexity and abstraction are correlated but distinct. A mathematical concept may be highly abstract without necessarily being perceived as difficult by every learner and a technically demanding problem may be manageable when it is connected to familiar examples (Onasanya & Areelu, 2023). Hence, this study would distinguish between perceived Banach space complexity and perceived mathematical abstraction and examines their respective relationships with students' attitudes.
- **Affective Gap:** Many studies of advanced mathematics often emphasize conceptual understanding, proof construction, and achievement (Moore et al, 2024). Hence, the specific ways in which students' perceptions of Banach spaces relate to their interest, confidence, motivation, anxiety, and persistence require further attention.

3. Methodology

3.1 Design, Population, Subjects and Instrument:

An ex-post factor survey research design was used for this study. It was conducted in two local government areas in Lagos State Nigeria. The population of the study comprised all mathematics and mathematics education graduates in six streams (A1, A2, B1, B2, C1, and C2) of National Youths Service Corps (NYSC) in the two local governments at the time of the study. National Youths Service Corps is a mandatory one-year program for Nigerian universities and polytechnics graduates set by the Federal Government of Nigeria. It is a scheme that every Nigerian graduate (which is under 30 years old at graduation) must complete before getting most formal jobs. Fifty mathematics NYSC members were randomly sampled from each of the local government. So, total of one hundred NYSC members were used as subjects for the study. The main instrument of this study is Banach Space Students Attitude Questionnaire. The questionnaire is made of three sections: A, B and C. Section A is on informed concept, the respondent has to indicate his/her interest in participating in the study and not to reveal his/her identity. Section B is on background information of the

respondent. Section C is on students' attitude towards higher mathematics and Banach space complexity and abstraction. The section C contains 52 items in 5 Likert-scale of Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D) and Strongly Disagree (SD). The instrument was validated by some experts in mathematics education. Pilot test was conducted on set of 30 NYSC mathematics members, test retest reliability coefficient of 0.871 was obtained which shown that the instruments is highly reliable.

3.2 Procedure

The subjects were contacted through their WhatsApp contacts collected from their officials in the local government. Message was sent to them to request for their consent to participate in the study. Online questionnaire was sent to them. Every one of them filled the questionnaire and returned it before a week interval deadline.

3.3. Ethical Considerations

Informed consent obtained from each participant. Participation was voluntary with option to withdraw and data were anonymized and securely stored.

4. Findings

4.1 Results

The first null hypothesis (H_{01}): Students do not perceive Banach space theory as more abstract or complex than other higher-level mathematics' topics.

One hundred (100) mathematics graduates participated in the study. The responses obtained from the participants were analyzed to determine whether their perceptions of Banach space theory differed significantly from their perceptions of other higher-level mathematics topics.

The scores were measured on a five-point scale, where higher scores indicate greater perceived abstraction or complexity. The descriptive statistics is on Table 1 below.

Table 1: Descriptive Statistics on Perceived Complexity of Banach Space Theory

Variables	N	Mean	Standard Deviation
Perceived complexity of Banach space theory	100	4.12	0.68
Perceived complexity of other higher-level mathematics topics	100	3.54	0.73
Difference		0.58	0.52

A paired-samples t-test was at the 0.05 level of significance. The results indicate that respondents rated Banach space theory as more abstract or complex than other higher-level mathematics topics. The mean score for Banach space theory was 4.12, compared with 3.54 for other advanced mathematics topics. The mean difference of 0.58 suggests that the perceived complexity of Banach space theory was appreciably higher.

Table 2: Paired-samples t-test for Perceived Complexity

Statistical measure	Result
Number of Respondents N	100
Mean Difference	0.58
Standard deviation of differences	0.52
Standard error of the mean difference	0.052
Calculated t-value	11.15
Degree of Freedom	99
Significance level, α	0.05
P-value	< 0.001
Remark & Decision	Significant, reject H_{01}

The calculated t-value of approximately 11.15 is statistically significant at the 0.05 level. The corresponding two-sided p-value is less than 0.001; the one-sided test specified by the directional alternative is also significant at this level. Therefore, the first null hypothesis is rejected. The result concludes that the respondents perceived Banach space theory as more abstract or complex than other higher-level mathematics topics.

The second null hypothesis (H_{02}): There is no significant relationship between students' attitudes toward Banach space theory and their motivation to learn advanced mathematics.

Pearson product-moment correlation coefficient was used to test the null hypothesis

Table 3: Descriptive Statistics for Attitude toward Banach Space Theory and Motivation to Learn Advanced Mathematics

Variables	N	Mean	Standard Deviation
Attitude toward Banach space theory	100	3.78	0.64
Motivation to learn advanced mathematics	100	3.91	0.67
Difference		0.13	0.51

The above results in table 3 indicate that the respondents had a mean attitude score of 3.78 and a mean motivation score of 3.91 on a five-point scale. These scores suggest generally positive attitudes toward Banach space theory and motivation to learn advanced mathematics, where higher scores indicate more positive attitudes and greater motivation.

Table 4: Pearson Correlation Analysis of Attitude and Motivation

Variable	N	Pearson's r	P-value	Remark & Decision
Attitude toward Banach space theory and motivation to learn advanced mathematics	100	0.62	< 0.001	Significant, reject H_{02}

Significance level: $\alpha = 0.05$.

The Pearson correlation coefficient is $r = 0.62$, indicating a moderately strong positive relationship between attitude toward Banach space theory and motivation to learn advanced mathematics. Since the p-value is less than 0.05, the relationship is statistically significant. So, the second null hypothesis is rejected.

The third null hypothesis (H_{03}): The perceived difficulty of Banach space theory does not significantly affect students' confidence or engagement in functional analysis.

Pearson correlation and multiple regressions were used to examine the relationship between perceived difficulty, confidence, and engagement. Pearson correlation was used to examine the relationship between perceived difficulty and confidence, while a second correlation examined perceived difficulty and engagement.

Table 5: Descriptive Statistics for Perceived Difficulty; Confidence, and Engagement in Functional Analysis

Variables	N	Mean	Standard Deviation
Perceived difficulty of Banach space theory	100	4.08	0.66
Confidence in learning Functional Analysis	100	3.12	0.71
Engagement in Functional Analysis	100	3.25	0.69

The table 5 shows that respondents reported a relatively high perceived difficulty score of 4.08, compared with mean scores of 3.12 for confidence and 3.25 for engagement. These figures suggest that respondents perceived Banach space theory as challenging, while their confidence and engagement were comparatively moderate.

Table 6: Correlation Analysis of Perceived Difficulty; Confidence, and Engagement in Functional Analysis

Relationship Examined	N	Pearson's r	p-value	Remark
Perceived difficulty and confidence	100	-0.46	< 0.001	Significant
Perceived difficulty and engagement	100	-0.39	< 0.001	Significant

Significance level: $\alpha = 0.05$.

Table 6 shows a statistically significant negative relationship between perceived difficulty and confidence ($r = -0.46$, $p < 0.001$). This indicates that respondents who perceived Banach space theory as more difficult tended to report lower confidence in learning functional analysis. Also, the correlation between perceived difficulty and engagement was negative and statistically significant ($r = -0.39$, $p < 0.001$). This implies that higher perceived difficulty tended to be associated with lower engagement in functional analysis. Since both p-values are below 0.05, the results provide evidence against the third null hypothesis. Therefore, the third null hypothesis is rejected. The results indicate that greater perceived difficulty is associated with lower confidence and engagement in functional analysis. The fourth null hypothesis (H_{04}): There is no significant difference in attitudes toward learning higher-level mathematics between students with high and low perceived understanding of Banach spaces.

Independent-samples t-test was used to test the null hypothesis. The 100 respondents are divided into two groups according to their perceived understanding of Banach spaces: 50 respondents in the high-understanding group and 50 in the low-understanding group. The classification was based on a clearly defined scoring rule established before examining the results.

Table 7: Descriptive Statistics for Attitudes toward Higher-Level Mathematics by Perceived Understanding

Group	N	Mean Attitude Score	Standard Deviation
High perceived understanding	50	3.92	0.55
Low perceived understanding	50	3.57	0.61
Difference		0.35	0.41

Table 7 shows that respondents with high perceived understanding of Banach spaces had a mean attitude score of 3.92, while those with low perceived understanding had a mean score of 3.57. The difference between the mean scores is 0.35 points, suggesting that the high-understanding group reported more positive attitudes toward learning higher-level mathematics.

Table 8: Independent-Samples t-Test for Differences in Attitude

Statistical measure	Result
High-understanding group, N	50
Low-understanding group, N	50
Mean difference	0.35
t-value	3.02
Degrees of freedom	98
p-value	0.003
Significance level	0.05
Remark & Decision	Significant, reject H_{04}

The independent-samples t-test produced a t-value of 3.02 with 98 degrees of freedom and a p-value of 0.003. Since the p-value is less than the 0.05 significance level, the difference between the two groups is statistically significant. The high-understanding group had a mean attitude score of 3.92, compared with 3.57 for the low-understanding group. This indicates that respondents who perceived themselves as having a higher understanding of Banach spaces reported more positive attitudes toward learning higher-level mathematics.

Hence, the fourth null hypothesis is rejected. The data shows a statistically significant difference in attitudes between the two groups.

4.2 Discussion

For the first hypothesis, the findings indicate that mathematics graduates perceived Banach space theory as significantly more complex than other higher-level mathematics topics. The mean score for perceived-complexity for Banach space theory was greater than the mean score for other advanced mathematics subjects. The paired-samples t-test further indicated a statistically significant difference between the two ratings.

This result shows that the mathematical characteristics of Banach space theory may present distinctive challenges to students studying advanced mathematics. Banach spaces have several interrelated concepts which include normed vector spaces, Cauchy sequences, convergence, and completeness. Students need to understand these concepts individually and also recognize how they combine to establish the defining properties of a complete normed vector space.

This finding is consistent with the conceptual perspective of Tall and Vinner (1981), who affirmed that students' mental representations of mathematical concepts may differ from their formal definitions. In the area of Banach spaces, a student may memorize the definition of completeness but struggle to explain why every Cauchy sequence must converge to an element of the space. Such a gap between formal knowledge and conceptual understanding may contribute to students' perception that the subject is difficult. This result also relates to cognitive load theory as developed by Sweller (1988) which explain how the demands imposed by learning materials interact with the limited capacity of working memory. Learning becomes more difficult when students must process many interacting elements simultaneously without adequate prior knowledge or instructional support. Understanding a proof involving completeness may require students to coordinate several concepts simultaneously. Where students have insufficient prior knowledge of sequences, norms, and convergence, these interacting demands may make learning more challenging. This interpretation suggests that students' perceptions of complexity may partly reflect the demands placed on their existing mathematical knowledge. In addition, the findings are broadly consistent with Häsä, Westlin, and Rämö (2023), whose research on undergraduate mathematical proving examined students' self-efficacy, anxiety, appreciation, and motivation. Their work highlights the importance of affective experiences in proof-based mathematics.

The second null hypothesis analysis suggests a statistically significant positive relationship between students' attitudes toward Banach space theory and their motivation to learn advanced mathematics. The correlation coefficient of 0.62 implies that respondents with more positive attitudes toward Banach space theory tended to report greater motivation to study advanced mathematical topics. This finding indicates that students' attitudes toward abstract mathematical subjects may be associated with their willingness to engage with challenging mathematical ideas. When students comprehend Banach space theory as manageable, meaningful, or intellectually rewarding, they may be more inclined to pursue further studies in functional analysis and other advanced areas of mathematics. This result can be discussed in relation to Bandura's (1997) self-efficacy theory, which emphasizes the importance of individuals' beliefs about their capabilities in influencing their choices, effort, and persistence. Learners who believe they can perceive and make progress in difficult mathematical subjects may be more willing to invest effort in learning them (Onasanya, 2021). The finding is also relevant to McLeod's (1992) explanation of affective domain of learning in mathematics education. Attitudes, beliefs, and emotional responses can be important aspects of learners' experiences of mathematics. In the context of Banach space theory, students' responses to abstraction, formal definitions, and proof-based reasoning may be associated with their motivation to continue learning higher-level mathematics. Also, the findings can be considered alongside Tall and Vinner's (1981) distinction between a student's concept image and formal concept definition. Banach space theory involves concepts such as normed vector spaces, completeness, Cauchy sequences, and convergence. If students develop useful mental representations of all these concepts and connect formal definitions with familiar mathematical examples, they can find the subject more approachable. However, these interpretations should be made cautiously. The correlation does not show in detail whether positive attitudes improve motivation, whether motivated learners develop more positive attitudes, or whether both are associated with other factors.

The third null hypothesis analysis reveals that students' perceived difficulty with Banach space theory is associated with their confidence and engagement in functional analysis. The negative relationship between perceived difficulty and confidence implies that learners who seem the subject highly abstract or complex may feel less capable of understanding definitions, following formal proofs, and solving related problems. The result is also in line with Sweller's (1988) cognitive load theory. The result also relates to Bandura's (1997) self-efficacy theory. Learners who doubt their ability to understand difficult mathematical concepts may be less willing to attempt challenging exercises or persist when they encounter difficulties. Nonetheless, the findings do not establish that perceived difficulty directly causes reduced confidence or engagement; since this analysis is correlational, other factors, may contribute to the observed relationships.

The fourth null hypothesis analysis reveals that perceived understanding of Banach spaces is associated with students' attitudes toward learning higher-level mathematics. This finding is consistent with Bandura's (1997) self-efficacy theory, which emphasizes the relationship between beliefs about personal capability and persistence in challenging tasks. Students who have confident that they can understand Banach space theory may be more inclined to approach advanced mathematics positively. The findings are in relation to Tall and Vinner's (1981) work on concept images and formal concept definitions. A student's understanding of Banach spaces involves more than memorizing definition but need to connect the definition with examples, counterexamples, convergence, and the reasoning used in proofs. Improving on these connections may support a more positive experience of abstract mathematics.

5. Conclusion and Recommendations

5.1 Conclusion

All the four null hypotheses for the study were rejected. The result shows that the respondents perceived Banach space theory as more abstract or complex than other higher-level mathematics topics. The finding suggests that more positive attitudes toward Banach space theory are associated with greater motivation to learn advanced mathematics. However, the relationship should not be

interpreted as evidence of causation. Also, the results suggest that greater perceived difficulty is associated with lower confidence and engagement in functional analysis. Finally, the result suggests that perceived understanding of Banach spaces is associated with differences in students' attitudes toward higher-level mathematics.

5.2 Recommendations

Banach space complexity and abstraction significantly influence students' attitudes toward learning higher-level's mathematics. Addressing these challenges requires a holistic approach that considers both cognitive and emotional factors in curriculum design. With reference to the findings, from an instructional perspective, mathematics lecturers need to provide deliberate support to students when introducing Banach space theory. They could begin with familiar examples, such as the real numbers with the usual norm, and then introduce more abstract spaces. Furthermore, lecturers need to

- Connect abstract ideas with familiar examples. Lecturers should introduce Banach spaces through familiar spaces before progressing to more advanced examples of normed function spaces.
- Encourage active participation of students. Guided exercises, group discussions, and opportunities to explain definitions and proofs may help students engage more meaningfully with abstract concepts.
- Build mathematical confidence progressively by breaking complex proofs into smaller steps and providing constructive feedback to class.
- Explain the relevance of the Banach spaces by showing how functional analysis is related to differential equations, optimization, and other mathematical applications. This may help students to appreciate the value of learning abstract mathematics.
- Use formative assessments and student feedback to identify areas in which learners experience persistent difficulty or disengagement.

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