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ANALYSIS OF STUDENTS MISCONCEPTIONS IN SOLVING QUADRATIC INEQUALITIES: A CASE STUDY IN THE INFORMATICS STUDY PROGRAM

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ABSTRACT

Strong mathematical foundations are crucial for informatics students, yet they frequently encounter difficulties with foundational topics such as quadratic inequalities, revealing a significant disconnect between procedural competence and conceptual understanding. This study investigates the nature and origins of misconceptions in solving quadratic inequalities among informatics students, using Vergnaud's Theory of Conceptual Fields as an analytical framework. A qualitative case study was conducted with 28 students from an Informatics Study Program. Data were collected through triangulation, including analysis of written solutions to five inequality problems and a self-report questionnaire featuring Likert-scale and open-ended questions. The analysis followed four stages: error identification, frequency profiling, cognitive scheme analysis, and representational analysis. Findings indicate that the most common errors were procedural, notably incorrect sign reversal when multiplying or dividing by a negative number (46.4% reported high difficulty) and misdetermining solution intervals for perfect square inequalities (39.3%). Conceptual errors were linked to underdeveloped cognitive schemes, especially in connecting critical points to interval testing and translating contextual problems into mathematical symbols.

ABSTRAK

Dasar matematika yang kuat sangat penting bagi mahasiswa informatika, namun mereka sering mengalami kesulitan dengan topik dasar seperti pertidaksamaan kuadrat, menunjukkan adanya kesenjangan yang signifikan antara kemampuan prosedural dan pemahaman konseptual. Studi ini menyelidiki sifat dan asal-usul kesalahpahaman dalam menyelesaikan petidaksamaan kuadrat di kalangan mahasiswa informatika, menggunakan Teori Lapangan Konseptual Vergnaud sebagai kerangka analisis. Studi kasus kualitatif dilakukan dengan 28 mahasiswa dari Program Studi Informatika. Data dikumpulkan melalui triangulasi, termasuk analisis solusi tertulis untuk lima soal pertidaksamaan dan kuesioner self-report yang mencakup pertanyaan skala Likert dan pertanyaan terbuka. Analisis dilakukan dalam empat tahap: identifikasi kesalahan, profil frekuensi, analisis skema kognitif, dan analisis representasi. Temuan menunjukkan bahwa kesalahan yang paling umum bersifat prosedural, terutama pembalikan tanda yang salah saat mengalikan atau membagi dengan bilangan negatif (46,4% melaporkan kesulitan tinggi) dan penentuan interval solusi yang salah untuk ketidaksetaraan kuadrat sempurna (39,3%). Kesalahan konseptual terkait dengan skema kognitif yang belum berkembang, terutama dalam menghubungkan titik kritis dengan pengujian interval dan menerjemahkan masalah kontekstual menjadi simbol matematika.

Kata kunci: *Pemahaman Konseptual; Pendidikan Informatika; Kesalahan Matematis; Pertidaksamaan Kuadrat; Teori Vergnaud*

INTRODUCTION

Strong mathematical problem-solving skills, fundamentally dependent on conceptual understanding, are indispensable for informatics students. The discipline demands competence in discrete logic, algorithmic processes, and precise problem modeling (Denning & Tedre, 2021). Within this domain, quadratic inequalities frequently act as a critical stumbling block that reveals deep-seated misunderstandings beyond mere calculation errors.

Global studies indicate that learners often fail to grasp essential inequality principles, particularly confusing rules governing inequalities with those applicable to equations (Jupri & Drijvers, 2016). These challenges persist in higher education, where students struggle with validating mathematical reasoning and modifying incorrect approaches (Alcock & Weber, 2005). In the Indonesian context, Palupi et al. (2022) found significant error rates in solving quadratic inequalities, attributing this to fragile conceptual foundations.

Traditional pedagogical methods focusing on procedural correction often fail to address underlying conceptual gaps. Research consistently shows that algebraic errors typically reflect unstable cognitive schemas rather than random mistakes (Makonye & Nhlanhla, 2014). This viewpoint is strongly corroborated by the work of Jupri and Drijvers, (2016) specifically link quadratic inequality struggles to deficits in conceptual knowledge, procedural execution, and representational translation.

While existing literature provides insights into general algebra errors, notable gaps remain. Previous studies primarily focus on equation-solving or secondary education contexts (Lozada et al., 2021; Baybayon & Lapinid, 2024). with scarce research examining mathematical misconceptions through informatics education lenses. This omission is critical, given informatics' unique cognitive demands requiring mathematical logic application to structured problem-solving and algorithm design (Denning & Tedre, 2021;Malmi et al., 2019). Although mathematical background crucially influences computing professionals' success (Alpers, 2017). specific competencies like inequality solving remain under-investigated. This study addresses this gap using Vergnaud's (2009) T heory of Conceptual Fields, which conceptualizes mathematical understanding through three interconnected components: situations giving concepts meaning, operational invariants (cognitive schemes), and symbolic representations. This framework is particularly suitable for investigating informatics students, whose training in discrete logic and algorithmic thinking—often binary in nature—may create unique cognitive challenges when dealing with continuous solution intervals in quadratic inequalities. The theory's integrated situation-scheme-representation approach provides a comprehensive analytical lens for moving beyond superficial error listing to uncover how fragile cognitive schemes and representational difficulties interact during problem-solving.

Guided by this theoretical framework, this research examines procedural and conceptual errors in informatics students' solutions to quadratic inequalities. The study aims to: (1) categorize and quantify error types, (2) investigate underlying cognitive schemes, and (3) analyze connections between formal definitions, problem contexts, and symbolic representations. Through triangulation of written solutions and self-reports, this inquiry seeks to develop nuanced understanding of informatics students' unique challenges, ultimately informing targeted pedagogical approaches that address foundational misunderstanding sources rather than superficial errors.

METHOD

Research Design and Participants

This study employed a qualitative case study approach with a descriptive-analytical orientation to investigate the structure of students' misconceptions in depth. The case was delineated within the context of a single Informatics Study Program. Participants consisted of 28 students from the IF-3 class who had recently completed an instructional module on quadratic inequalities. Purposive sampling was utilized to select individuals who had both enrolled in the relevant course and submitted complete responses to all problem-solving tasks. This sample size was determined adequate for yielding rich, analytical insights into the phenomenon, consistent with qualitative research objectives rather than statistical generalization.

Research Instruments

Data were collected through methodological triangulation comprising two primary instruments:

1. Written Mathematics Test: Participants completed five inequality problems designed to elicit various types of procedural and conceptual misconceptions (see Appendix A for complete instrument). The problems encompassed:
   a. Polynomial inequalities with repeated roots
   b. Basic quadratic inequalities
   c. Linear inequalities
   d. Compound inequalities
   e. Absolute value inequalities
2. Self-Report Questionnaire: A validated instrument utilizing Likert scales and open-ended questions assessed students' perceived difficulties. The questionnaire was validated through expert judgment by two mathematics education specialists, achieving a Content Validity Index (CVI) of 0.85, confirming its relevance, clarity, and appropriateness for the research objectives.

Data Analysis Framework

The analytical process was guided by Vergnaud's (2009) Theory of Conceptual Fields, which examines the dynamic interactions among: (1) the situation (specific inequality problems presented), (2) operational invariants (implicit cognitive schemes guiding solution attempts), and (3) representational systems (mathematical symbols and notations used).

Guided by this theoretical triad, data analysis progressed through four sequential yet reflexive stages:

1. Error Identification and Classification: Initial phase involved meticulous examination of written solutions to identify and categorize inaccuracies. Errors were classified as procedural (flawed execution of algebraic steps, e.g., incorrect factoring) or conceptual (fundamental misunderstanding of inequality principles, e.g., misinterpreting solution sets of perfect squares).
2. Frequency Profiling: Quantitative analysis of questionnaire responses generated profiles of self-reported difficulties, complementing data from actual problem-solving performance.
3. Analysis of Underlying Schemes: This stage investigated why errors occurred by analyzing mistake patterns across different problems and triangulating with self-reported data. To ensure trustworthiness, researchers conducted peer debriefing sessions, critically discussing inferred cognitive schemes until consensus was reached.
4. Representational Analysis: Final step assessed students' fluency in connecting mathematical concepts to their representations, examining alignment between stated understanding, applied procedures, and problem requirements.

Research Procedure

The research procedure is visually summarized in Figure 1. The process begins with establishing theoretical grounding, followed by parallel data collection through methodological triangulation. The central component involves applying Vergnaud's theory across four analytical stages to synthesize data and reveal the architecture of students' misconceptions, culminating in findings synthesis, discussion, and educational implications.

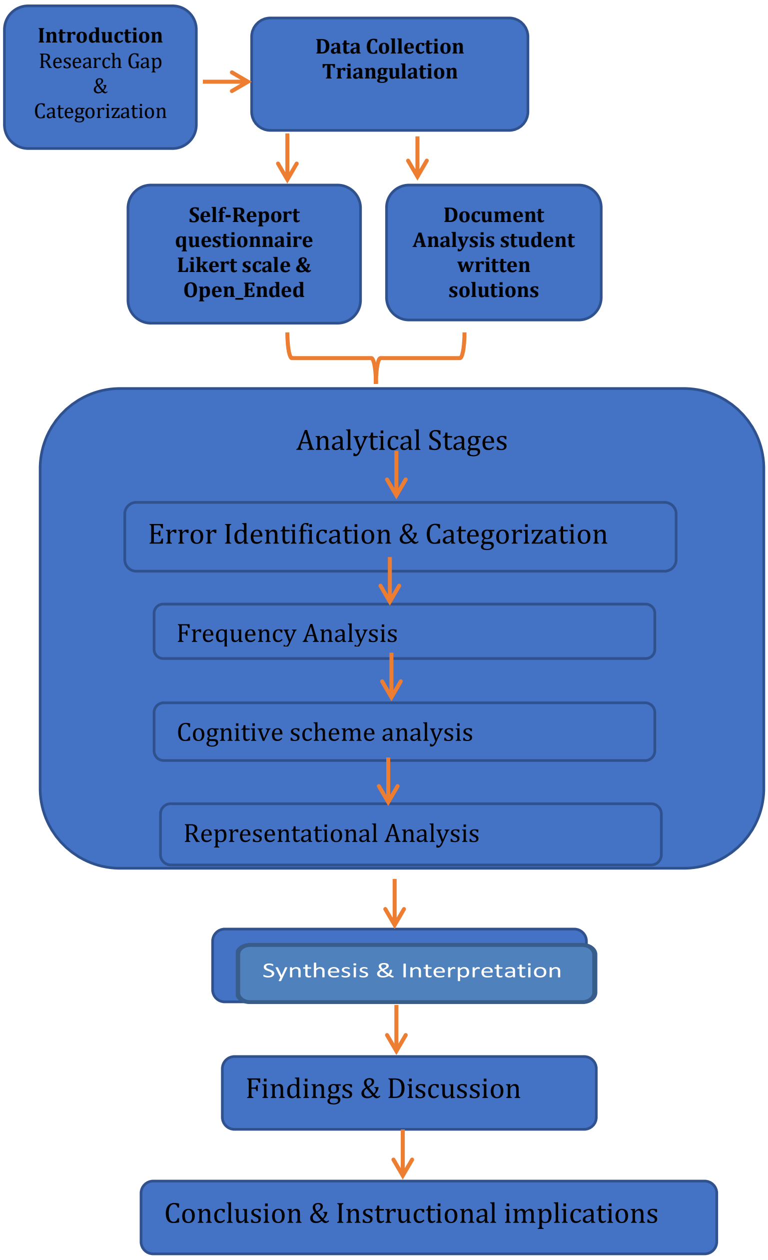

Figure 1. The research procedure

Ethical Considerations

The study adhered to standard ethical protocols for educational research. Prior to data collection, informed consent was obtained from all participants, granting permission for use of anonymized academic work. All personally identifiable information was removed from the dataset, and participants were referenced only by anonymized codes throughout the research process.

RESULTS

The triangulation of survey data and written solutions revealed consistent patterns in student challenges. As summarized in Table 1, reversing inequality signs and determining solution intervals for perfect square inequalities were perceived as the most difficult tasks, with 46.4% and 39.3% of students respectively reporting high difficulty levels.

Table 1. Self-Reported Difficulty Frequencies

Difficulty	Mean Score	SD	% High Difficulty
Sign Reversal	3.07	1.15	46.4%
Contextual Translation	3.29	1.24	35.7%
Perfect Square Intervals	3.25	1.32	39.3%
Critical Points	3.21	1.18	35.7%
Factoring	3.14	1.42	32.1%
Interval Notation	3.11	1.25	28.6%

Qualitative Analysis of Documented Errors

1. Procedural Errors in Inequality Sign Manipulation

Analysis of written solutions confirmed sign reversal as the most prevalent procedural error (46.4%, n = 13). When solving $-x^2 + 4x - 3 > 0$, students typically multiplied by -1 but failed to reverse the inequality sign. For instance, one student correctly transformed the inequality to $x^2 - 4x + 3 > 0$ and factored it as $(x - 1)(x - 3) < 0$, but incorrectly concluded the solution was x < 1 or x < 1, demonstrating fundamental misunderstanding of interval analysis where the correct solution should be 1 < x < 3.

2. Conceptual Errors in Perfect Square Inequalities

A profound conceptual gap emerged in solving $(x - 2)^2 < 0$, where 35.7% (n = 10) of students incorrectly concluded x = 2 as the solution. This indicates misapplication of equation-solving principles to inequalities, failing to recognize that squared expressions are always non-negative. Open-ended responses revealed this confusion, with one student noting: "I thought since $(x - 2)^2$ becomes zero at x = 2, that should be the answer."

3. Case Analysis: Procedural Failure in Interval Testing

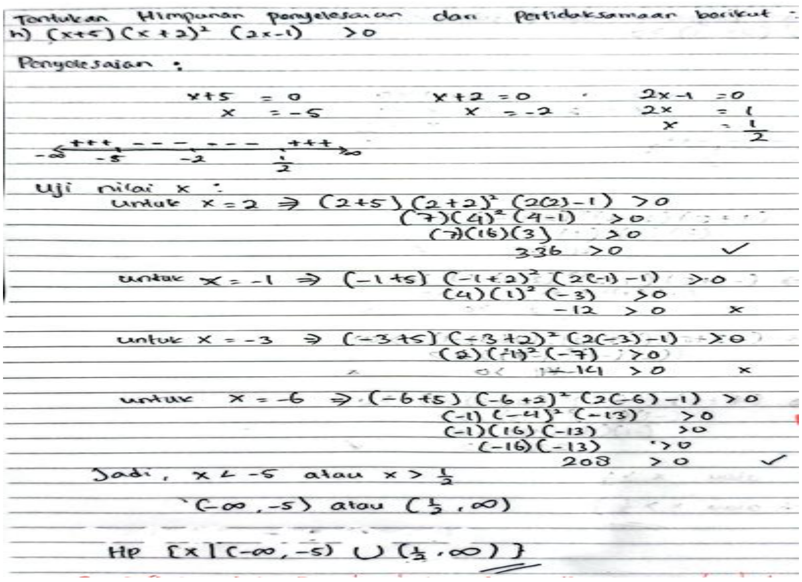

Figure 2. Student's solution showing computational errors in interval testing

Analysis of a student's solution to $(x+5)(x+2)^2(2x-1) > 0$ (Figure 2) revealed systematic procedural weaknesses. When testing x = -3, the student wrote: $(-3+5)(-3+2)^2(2(-3)-1) > 0$ → $(8)(14)^2(-7) > 0$ → $-14 > 0$ (Incorrect)

Two critical errors were identified:

1. Computational error: (-3+2) = -1, not 14
2. Logical error: Concluding -14 > 0 is true

The cognitive scheme for "test points" was applied mechanically without conceptual understanding of inequality meaning or computational accuracy.

4. Disconnect Between Process and Representation

For the same problem, despite incorrect test results, the student arrived at the correct final solution: x < -5 or x > 1/2

Analysis through Vergnaud's Lens:

- **Situation**: Determining intervals where product is positive
- **Scheme**: Conflict between active "root finding" scheme and failed "sign analysis" and "inequality logic" schemes
- **Representation**: Correct final notation (-∞, -5) ∪ (1/2, ∞) despite flawed process representation, indicating fragmented understanding

5. Confusion in Mathematical Notation

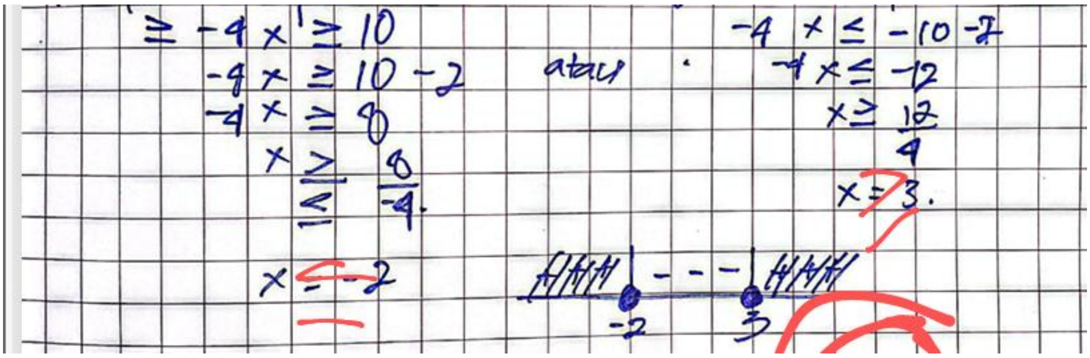

Figure 3. Student's repeated notation indicating conceptual uncertainty

Analysis of linear inequality solutions revealed persistent notational confusion. As shown in Figure 3, one student repeatedly wrote -4 < x < 3 before concluding with interval notation (-4, 3), suggesting uncertainty about notation meaning and boundary interpretation.

Emerging Pattern: Logic-Procedure Disconnect

Cross-analysis revealed students reporting high difficulty with "Critical Points & Testing" (35.7%) often demonstrated disconnects between algebraic manipulation and logical reasoning. For example, after correctly factoring $x^2 + x - 12 > 0$ into $(x-4)(x+3) > 0$, some students tested x = 0 but misapplied results, leading to invalid interval conclusions. This suggests underdeveloped cognitive schemes for linking critical points to function signs across intervals, shown in Figure 4.

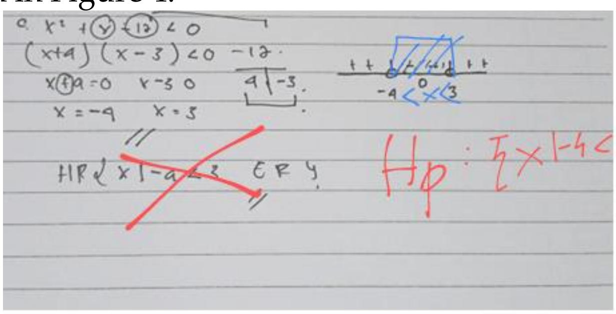

Figure 4. After correctly factoring an expression like $x^2 + x - 12 > 0$

DISCUSSION

Through the theoretical lens of Vergnaud's (2009) conceptual fields, the prevalent sign reversal error (46.4%) emerges not as a procedural oversight but as a manifestation of deeper cognitive issues. While this finding aligns with existing research on the universal difficulty with inequality sign rules (Jupri & Drijvers, 2016) the present study advances understanding by identifying its cognitive origins. The error pattern reveals a fundamental operational invariant wherein students inappropriately apply equation-solving schemes to inequality contexts, rendering the sign reversal rule an isolated procedural step rather than an integrated conceptual understanding.

The analysis of written solutions, particularly as evidenced in Figure 2, substantiates this interpretation. Procedural errors such as the assertion that $-14 > 0$ represent not random miscalculations but systematic consequences of dominant equation-solving schemas. Within these cognitive frameworks, students prioritize algebraic manipulation over logical analysis, explaining why rules requiring conceptual understanding remain vulnerable to misapplication.

A more profound conceptual deficit emerged in students' approaches to perfect square inequalities like $(x-2)^2 < 0$. The predominant solution of $x = 2$ indicates students' reliance on root-finding schemes while neglecting the essential mathematical property of non-negativity for squared expressions. This finding corroborates Jupri & Drijvers' (2016) emphasis on representational flexibility, as students demonstrated inability to transition from algebraic manipulation to graphical or logical reasoning modes. Particularly noteworthy for this informatics cohort was the observed compartmentalization of knowledge, wherein computational logic training failed to transfer to mathematical contexts, revealing a disconnect between informatics and mathematical symbolic systems.

Further evidence of conceptual fragmentation appears in students' difficulties with contextual problems and interval notation, illustrating a rupture between Vergnaud's situational and symbolic representation components. While students could typically identify critical points from problem contexts, they struggled to map these to appropriate solution intervals, echoing challenges identified in prior research by Palupi et al. (2022). These findings collectively advocate for pedagogical approaches that explicitly scaffold the reasoning process, requiring students to articulate how situational elements inform critical point selection and subsequent symbolic representation.

CONCLUSION

This study, framed by Vergnaud's Theory of Conceptual Fields, has systematically identified and analyzed the procedural and conceptual barriers informatics students encounter with quadratic inequalities. The evidence confirms that frequent errors—particularly in sign reversal and perfect square interpretation—represent systematic manifestations of underdeveloped cognitive schemes rather than isolated computational errors. The central challenge appears to be students' persistent inability to integrate algebraic procedures with logical reasoning and graphical representation.

The diagnostic insights from this analysis provide specific, actionable guidance for informatics education pedagogy. Instruction must transcend procedural repetition to deliberately cultivate the triadic relationship fundamental to conceptual understanding. Specifically, educators should: (1) integrate visual tools including number lines and function graphs to contextualize abstract concepts; (2) implement logical reasoning exercises that precede algebraic manipulation; and (3) design problem-solving activities requiring explicit justification of each step with reference to core mathematical properties.

This study's limitation to a single academic program necessitates cautious generalization of findings. Future research should validate these diagnostic patterns across more diverse informatics and computer science populations. Additionally, promising research directions include designing and evaluating longitudinal interventions based on the identified cognitive gaps to assess their efficacy in addressing these deeply embedded misconceptions.

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