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TRANSITION FROM PAPER-BASED WORKSHEETS TO SPREADSHEETS: AN EXPLORATORY STUDY OF OPPORTUNITY TO LEARN IN LINEAR ALGEBRA INSTRUCTION

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Abstract: This study explores the impact of transitioning from traditional paper-based worksheets to spreadsheet-based instruction on students' Opportunity to Learn (OTL) in a Linear Algebra course. Conducted with 37 undergraduate mathematics education students, the research employed a qualitative exploratory approach to examine changes in student engagement, conceptual understanding, and pedagogical awareness. The intervention began with procedural paper-based tasks and gradually introduced spreadsheet environments designed to foster conceptual exploration and mathematical argumentation. Data were collected through observations, student artifacts, and interviews, and analyzed using content analysis and learning trajectory comparison. The findings reveal that spreadsheet-based instruction enhanced computational accuracy, facilitated independent exploration, and promoted metacognitive engagement. A comparison between the hypothetical learning trajectory (HLT) and actual learning pathway (ALT) showed that students exceeded expectations, demonstrating improved conceptual reasoning and reflective thinking. The study concludes that spreadsheet integration—when embedded in argumentation-based learning—serves as a transformative pedagogical tool, expanding instructional quality and deepening students' opportunity to learn in higher mathematics education.

Key words: Opportunity to Learn, Spreadsheet-Based Learning, Linear Algebra, Argumentation, Learning Trajectory

1. Introduction

Linear Algebra is a fundamental component of undergraduate mathematics education, serving as a cornerstone for various disciplines including engineering, computer science, and data analysis (Catarino & Vasco, 2021; Stewart & Thomas, 2019). However, students often encounter difficulties in grasping its abstract concepts, such as vector spaces and matrix operations, which can impede their overall comprehension and application skills (AÇIKYILDIZ & KÖSA, 2021; Yanti et al., 2022).

Traditional instructional methods, predominantly relying on paper-based worksheets, emphasize procedural proficiency but may fall short in fostering deep conceptual understanding (Arslan, 2010; A. Moore & Caruso, 2020; J. P. Moore et al., 2013). These approaches often lack dynamic visualization and immediate feedback mechanisms, which are crucial for engaging students in meaningful learning experiences (Kolb & Kolb, 2008; Martin, 2018; Musa & Zulkafly, 2017).

The integration of technology, particularly spreadsheets, into mathematics education has shown promise in addressing these challenges (Haspekian & Bruillard, 2010). Spreadsheets offer interactive platforms that facilitate the exploration of mathematical concepts through real-time data manipulation and visualization, thereby enhancing students' engagement and understanding (Mary Osei Fokuo et al., 2023). Research indicates that utilizing spreadsheets in teaching algebra can aid students in developing a more profound comprehension of mathematical relationships and structures (Becheru et al., 2018; Ion & Popescu, 2024).

Moreover, incorporating argumentation-based instructional models within spreadsheet environments can further enrich the learning process. Such models encourage students to articulate reasoning, justify solutions, and engage in critical thinking, which are essential skills in mathematics education. Studies have demonstrated that argumentation fosters a deeper understanding of mathematical concepts and

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promotes the development of higher-order thinking skills (Hadianto et al., 2021; Okumus & Unal, 2012).

In this context, the concept of Opportunity to Learn (OTL) becomes pertinent. OTL refers to the extent to which educational settings provide students with the necessary resources, time, and instructional quality to learn effectively (Kurz et al., 2014; Liu & Whitford, 2011; Wijaya et al., 2015). Transitioning from paper-based worksheets to spreadsheet-based instruction, coupled with argumentation strategies, has the potential to enhance OTL by offering more interactive, reflective, and student-centered learning experiences (Alexandrovsky, 2018; Procter, 2020).

This study aims to explore the impact of transitioning from traditional paper-based worksheets to spreadsheet-based instruction on students' Opportunity to Learn in Linear Algebra courses. By examining the integration of argumentation-based learning within spreadsheet environments, the research seeks to identify how such pedagogical shifts influence students' conceptual understanding, engagement, and overall learning outcomes.

2. Method

This study adopted a qualitative exploratory approach to investigate the effects of transitioning from paper-based worksheets to spreadsheets on students' Opportunity to Learn (OTL) in Linear Algebra instruction. The research was conducted in a second-semester Linear Algebra course at Universitas Negeri Makassar, involving 37 undergraduate students enrolled in the mathematics education program. These participants were selected purposively, as they were actively engaged in the course and willing to participate in the study.

The learning intervention was designed to allow students to explore core Linear Algebra concepts—particularly systems of linear equations and matrix operations—using both traditional and digital tools. The instructional design began with tasks using paper-based worksheets that emphasized procedural understanding and step-by-step problem solving. After these initial sessions, students were gradually introduced to spreadsheet-based learning environments, where they explored the same mathematical content using Microsoft Excel. This transition was intended not only to enhance computational efficiency but also to foster conceptual engagement and mathematical argumentation.

To capture the learning process and its impact on students, data were collected through classroom observations, analysis of student worksheet artifacts, and semi-structured interviews. Observational data focused on student behavior, instructional strategies, and the flow of classroom interaction during both the manual and digital phases of the intervention. Student work, in both formats, was examined to identify levels of conceptual understanding, strategy use, and evidence of mathematical reasoning. In addition, semi-structured interviews were conducted with selected students to gather their reflections on the learning experience, including their perceptions of the spreadsheet environment and its influence on their thinking and problem-solving processes.

The data were analyzed using qualitative content analysis. Patterns of engagement, instructional change, and student reflection were identified and categorized. The triangulation of data from observations, artifacts, and interviews allowed for a comprehensive interpretation of how the digital transition influenced the depth, efficiency, and interactivity of students' learning opportunities in the context of Linear Algebra.

3. Results and Discussion

The transition from paper-based worksheets to spreadsheets in Linear Algebra learning offered significant changes in the way students engaged with mathematical concepts, particularly in terms of their Opportunity to Learn (OTL). The designed learning trajectory consisted of five tasks. Tasks 1 to 4 focused on matrix identification and construction through paper-based activities, drawing on students' prior knowledge of elimination and substitution methods. These tasks activated existing schemas and encouraged collaborative problem-solving. This is reflected in Tabel 1 (Learning Tasks Overview), which documents the distribution of learning goals across manual and digital phases.

Table 1. *Hypothetical Learning Trajectory for Matrix Concepts in Linear Algebra*

Learning Goals	Student Activities	Mathematical Focus	Media / Representation
1. Identify matrix concepts in linear systems using prior knowledge from secondary education	Recall and discuss elimination and substitution methods collaboratively	Procedural understanding of matrix representations	Paper-based worksheet, peer discussion
2. Construct the characteristics of matrices based on given contextual problems	Analyze matrix form in contextual problems; define rows, columns, and dimensions	Structure and components of matrices	Paper-based worksheet, verbal explanation
3. Operate matrices using spreadsheet formulas (e.g., addition, multiplication)	Input matrices into spreadsheet; perform operations using formulas	Operations on matrices (addition, multiplication)	Spreadsheet (Excel/Google Sheets)
4. Interpret results of matrix operations and identify patterns through digital manipulation	Observe output tables; compare manual and automated results; discuss emerging patterns	Conceptual generalization of matrix behavior	Spreadsheet tables and formula outputs
5. Reflect on advantages of spreadsheet-based vs. manual matrix procedures	Evaluate ease, accuracy, and efficiency; respond to guiding reflection questions	Metacognitive awareness of learning tools	Oral reflection, short written summary

Observation data from early sessions indicated that students were comfortable with paper-based formats. They actively discussed solutions, shared strategies, and supported one another while completing matrix problems using manual calculations. The classroom environment was described as relaxed and collaborative.

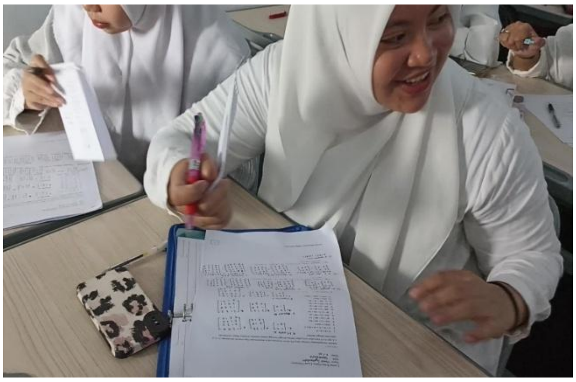

Figure 1 *Paper-Based Worksheet Activities*

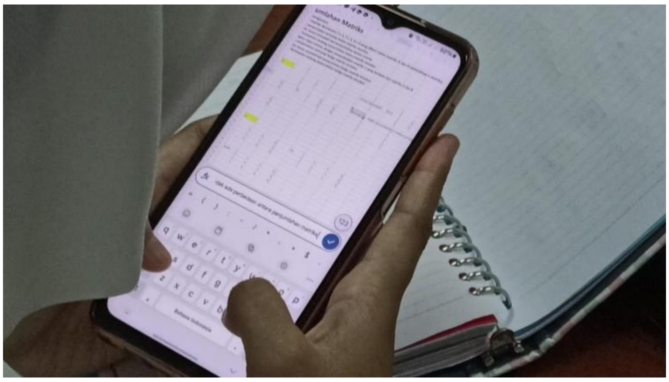

Figure 2 *Spreadsheet-Based Activities*

The transition from paper-based worksheets to spreadsheet-based instruction in Linear Algebra significantly influenced students' learning behaviors and conceptual development. The instructional design incorporated five structured tasks. Tasks 1 through 4 engaged students in identifying and reconstructing the concept of matrices within systems of linear equations using traditional paper formats. This phase was designed to reinforce students' prior procedural knowledge and foster collaborative problem-solving.

As illustrated in Figure 1, students were actively engaged in small-group discussions while solving matrix problems manually. This setting promoted procedural fluency and supported social interaction as students verbalized their reasoning and shared strategies. However, as students progressed to Task 5, the instructional modality shifted to spreadsheet-based learning. Students began working more independently using spreadsheet software on their smartphones or laptops.

This transition marked a substantial change in student engagement and problem-solving approaches. As captured in Figure 2, students were seen interacting directly with digital tools. Unlike the collaborative paper phase, this stage was characterized by self-directed learning and heightened cognitive focus. Students leveraged spreadsheet functions—such as cell referencing and matrix multiplication—to automate complex calculations. Field notes highlighted improvements in task completion time, accuracy, and student confidence. Nonetheless, a slight reduction in peer interaction was observed as attention became more individually focused.

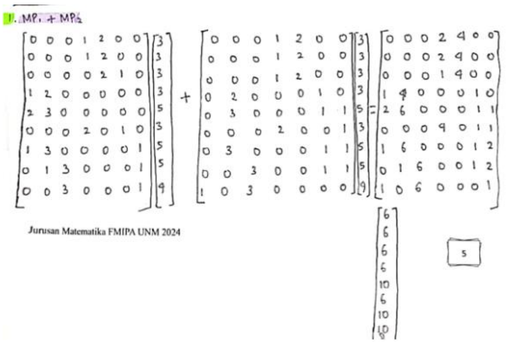

Figure 3. *Paper Worksheet Answers*

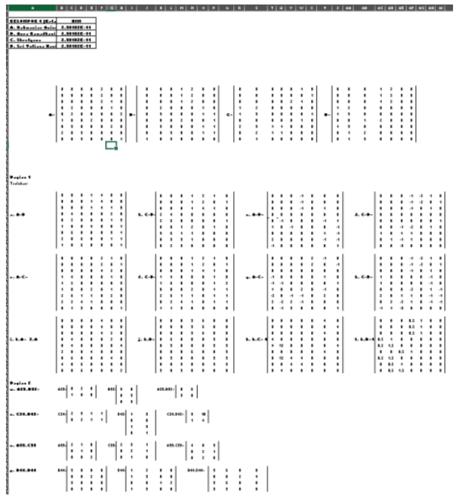

Figure 4. *Spreadsheet Worksheet Answers*

Figures 3 and 4 further illustrate the contrast between manual and digital learning approaches. Figure 3 shows a student's handwritten matrix solution using a paper worksheet. The matrix is written line by line, with manual calculations noted in the margins. While this method encourages transparent step-by-step reasoning and makes the student's thought process visible, it is also prone to computational errors, particularly in repetitive tasks such as elementary row operations. These errors can interrupt conceptual fluency and increase cognitive load.

In contrast, Figure 4 presents a student's solution using a spreadsheet. The structure is more systematic, with matrix entries clearly aligned in rows and columns. Students employed spreadsheet formulas to automate calculations, which enhanced their accuracy and freed cognitive resources for higher-order reasoning—such as pattern recognition, strategic comparison of methods, and reflective evaluation. Through the spreadsheet interface, students were also able to explore variations of the same problem more efficiently and visualize transformations dynamically. These differences suggest that spreadsheet-based learning supported a more precise, organized, and exploratory engagement with matrix operations.

Analysis of student worksheet artifacts supported these observations. Paper-based submissions revealed procedural steps but often lacked consistency and precision. In contrast, spreadsheet-based artifacts were cleaner, more structured, and demonstrated better comprehension of matrix operations through logical sequencing and correct use of formulas.

These interpretations were reinforced by data from semi-structured interviews. Students confirmed that they were introduced to spreadsheet tools in the fourth meeting and began using them independently by the fifth. One student, Aura, reflected on her experience comparing the elimination and substitution methods she had learned in school with the Elementary Row Operation (ERO) method used in the spreadsheet environment:

> "The ERO method is more structured when used in spreadsheets. If it's just two variables, elimination might be fine. But when there are three or more variables, ERO is easier to apply."

This sentiment illustrates how the digital tools facilitated learning of more complex systems and enabled students to evaluate and choose efficient strategies—an indicator of metacognitive engagement. Another student emphasized the flexibility and error-handling advantages of spreadsheets:

> "Using ERO with spreadsheets is faster and easier. I don't need to keep repeating calculations if I make a mistake. The spreadsheet just recalculates everything for me."

Beyond technical skill, the learning also had implications for students' professional identity as future teachers. One participant noted:

> "As a prospective teacher, this kind of task is useful. I now understand not just how to solve matrix problems, but also how I might teach them more effectively using spreadsheets."

These reflections confirm that the intervention not only improved mathematical reasoning but also shaped pedagogical awareness. The spreadsheet-based phase was not a mere technological shift but represented a pedagogical transformation—fostering greater independence, flexibility, and conceptual grounding.

Finally, retrospective analysis of the actual learning trajectory (ALP) compared to the hypothetical design (HLT) showed that students exceeded the intended outcomes. They demonstrated increasing autonomy, precision, and reflective thinking throughout the digital phase. This suggests that spreadsheet-based instruction enhanced their opportunity to learn (OTL) by promoting efficient time use, dynamic interaction with content, and learner-centered engagement.

Table 2. *Matrix Analysis: Comparison of HLT and ALT in Linear Algebra Learning*

Learning Component	**Hypothetical Learning Trajectory (HLT)**	**Actual Learning Trajectory (ALT)**	**Remarks**
Learning Objectives	Students identify and construct matrix concepts through manual contextual problems; later, operate matrices using spreadsheets.	Students exceeded initial goals by integrating conceptual understanding with strategic thinking and teaching reflection.	ALT showed broader cognitive outcomes, including pedagogical insight and metacognitive engagement.
Media Used	Paper-based worksheets (Tasks 1–4), spreadsheets (Task 5).	Paper worksheets followed by dynamic spreadsheet use across Tasks 4 and 5.	Spreadsheet use began earlier and became central to learning.
Student Activities	Structured problem-solving with group discussion (manual), followed by individual spreadsheet tasks.	Collaborative engagement in early tasks; individual, exploratory, and reflective tasks in digital phase.	Higher autonomy and individual focus emerged in ALT.
Interaction Type	High student-to-student interaction expected in manual phase; limited in digital tasks.	Observed strong peer collaboration initially, then a shift to self-directed learning in digital tasks.	Transition in interaction mode confirmed.
Cognitive Demand	Focused on procedural fluency and structured conceptual engagement.	Expanded into strategy comparison, error-checking, and reasoning with digital tools.	ALT showed higher-level thinking and flexibility in method evaluation.
Tools and Techniques	Manual computation for initial understanding; spreadsheets for automation and efficiency.	Spreadsheet tools used not only for automation but also for exploration, visualization, and metacognitive analysis.	Tools became cognitive amplifiers, not just computational aids.
Evidence of Understanding	Expected through written steps and answers; clarity assumed from structure of tasks.	Evident from structured digital outputs, correct use of formulas, and interview reflection about problem-solving strategies and teaching potential.	ALT provided more visible and multidimensional evidence of learning.
Learning Outcomes	Mastery of matrix procedures and operations; basic digital literacy.	Mastery of matrix concepts, enhanced digital fluency, strategy awareness, and teaching applicability.	Learning outcomes broadened significantly in ALT.
Instructional Alignment	Sequential task design assumed sufficient for conceptual progression.	Instructional adaptation occurred (earlier spreadsheet integration, deeper reflection), aligning better with student needs.	Teacher's adaptive decisions enriched the learning process.

A comparative analysis between the Hypothetical Learning Trajectory (HLT) and the Actual Learning Trajectory (ALT) reveals meaningful expansions in student learning that emerged during the instructional process. While the HLT envisioned a sequential development—from manual identification of matrix concepts to digital operation using spreadsheets—the ALT demonstrated a broader trajectory. Students not only mastered the intended procedural and conceptual content, but also showed increased autonomy, adaptability, and metacognitive engagement. Their interaction with spreadsheets evolved from simple computation to exploratory learning, where digital tools were used to identify patterns, evaluate strategies, and construct logical arguments (Chen et al., 2020). This progression was not explicitly anticipated in the original HLT but became a defining feature of the actual learning experience.

Furthermore, the ALT indicated deeper cognitive and pedagogical outcomes than originally planned. Students' reflections revealed a growing awareness of instructional strategies, as many began to connect their learning with future teaching practice. Their ability to compare methods, justify solution paths, and recognize instructional affordances of spreadsheet tools suggested a dual focus: learning mathematics and learning how to teach it. The teacher's adaptive actions—such as introducing spreadsheet use earlier and encouraging exploratory tasks—further aligned instruction with emerging student needs. This flexible implementation enriched the OTL by expanding the dimensions of time, content, and instructional quality (Byrnes & Miller, 2007; Marion, 2020; Wang et al., 2022). Thus, the ALT did not merely follow the planned path but extended it, illustrating the dynamic interplay between instructional design, student agency, and digital media in higher mathematics education.

This study aimed to explore the impact of transitioning from traditional paper-based worksheets to spreadsheet-based instruction on students' Opportunity to Learn (OTL) in Linear Algebra courses. The findings indicate that this pedagogical shift not only enhanced computational efficiency but also significantly improved students' conceptual understanding, engagement, and overall learning outcomes (Gadanidis et al., 2022; Ng & Cui, 2020). The integration of spreadsheet tools transformed routine procedural tasks into opportunities for exploration, reflection, and strategic comparison of mathematical methods. This observation supports prior research asserting that spreadsheets, when used meaningfully, can foster students' engagement with mathematical structures and promote higher-order thinking (Barana, 2022; Nasrullah; Baharman, 2018).

The incorporation of argumentation-based learning within the spreadsheet environment played a pivotal role in this transformation. By encouraging students to justify their choice of methods (e.g., elimination vs. ERO), reflect on their problem-solving processes, and articulate their reasoning, the instructional model promoted deeper conceptual engagement. This aligns with findings from (Nasrullah, 2022; Nasrullah & Zulkardi, 2011), who emphasized that structured argumentation enhances students' mathematical reasoning and fosters better conceptual retention. Moreover, the use of spreadsheets allowed students to visualize transformations dynamically (Assis, 2021; Hermans et al., 2012), test multiple strategies efficiently, and engage in metacognitive evaluation of their learning processes (Jordano, 2018; Kjeldsen & Blomhøj, 2012).

The observed learning outcomes extended beyond the expectations of the hypothetical learning trajectory. Students not only achieved procedural fluency and conceptual depth but also developed pedagogical awareness (Cancino & Oyarzún, 2025; Mkundi & Mulema, 2024) Their reflections on how spreadsheet-based approaches could support future classroom teaching indicate a transfer of knowledge from learner to teacher identity. This reinforces the argument that well-integrated technology in mathematics teacher education supports the development of both content understanding and pedagogical thinking (Hughes & Tight, 2021; Sulaiman et al., 2024).

In summary, the integration of argumentation-based learning within spreadsheet environments positively influenced students' conceptual understanding, engagement, and overall learning outcomes. It also expanded their Opportunity to Learn by improving time efficiency, deepening content exploration, and enhancing the quality of instructional interaction. These findings suggest that transitions from conventional to digital learning models, when designed intentionally, can serve as transformative pedagogical innovations in higher mathematics education.

4. Conclusion

This study explored the effects of transitioning from traditional paper-based worksheets to spreadsheet-based instruction on students' Opportunity to Learn (OTL) in a Linear Algebra course. The findings reveal that this transition, when embedded in an argumentation-based instructional framework, significantly enhanced students' engagement, conceptual understanding, and pedagogical awareness. The use of spreadsheets shifted the learning environment from procedural and teacher-directed to exploratory and student-centered, allowing learners to visualize matrix operations, test multiple strategies, and engage in metacognitive reasoning.

Moreover, the comparison between the hypothetical and actual learning trajectories demonstrated that students exceeded initial expectations. They not only mastered the intended mathematical content but also developed the ability to critically evaluate learning tools and reflect on their potential application in teaching contexts. These outcomes affirm the role of digital tools like spreadsheets as transformative instruments in mathematics education, capable of broadening instructional quality, deepening content engagement, and enhancing students' overall learning opportunities. The study contributes to the growing body of research on technology integration in teacher education and highlights the importance of designing digital transitions that align with pedagogical goals and promote reflective professional growth.

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