

## Leveraging Contextual Worksheet to Reveal Students' Proof in Counting Rules

Gusti Uripno<sup>1\*</sup>, Edy Nurfalah<sup>1</sup>

<sup>1</sup>Universitas PGRI Ronggolawe Tuban, Indonesia

[gustidash@gmail.com](mailto:gustidash@gmail.com)

\*Corresponding author

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### **Abstract:**

This study aims to explore how contextualized combinatorics tasks set within a cinema-themed worksheet support undergraduate students' transition from concrete enumeration strategies to formal combinatorial reasoning through a qualitative case study design. Combinatorics and permutation rules are included in this research. Participants engaged with four scaffolded tasks that first had them list seating arrangements for three friends and subsequently required them to explain the principles governing ordered versus unordered selections, while their written responses and verbal protocols were analyzed using thematic coding of representational approaches and justification quality. Findings reveal that embedding tasks in a familiar narrative and providing multimodal supports such as tables and color-coded diagrams helped students explicitly identify variables, assumptions, and logical steps, enabling them to construct factorial-based arguments without reliance on rote computation. Although all participants ultimately derived correct combinatorial solutions, the depth and clarity of their proofs varied in relation to individual verbal reasoning skills, and common misconceptions were effectively addressed when scenarios contrasted ordered and unordered cases. This single-paragraph abstract highlights that progressively reducing concrete scaffolds within real-world contexts enhances both engagement and conceptual understanding in discrete mathematics, suggesting that culturally relevant narratives and adaptive supports merit further investigation in larger-scale, mixed-methods studies.

**Keywords:** Contextual Combinatorics Problem; Combinatorial Thinking; Mathematical Proof.

### **Introduction**

Combinatorics is a fundamental area of discrete mathematics that focuses on counting, arrangement, and selection of objects (Lockwood, Wasserman, et al., 2020). It provides a structured framework to determine how objects can be grouped, ordered, or chosen. In the context of mathematics education, combinatorial principles such as the sum and product rules, permutations, and combinations are critical for developing students' reasoning and abstract thinking skills (Uripno & Rosyidi, 2019). As modern curricula in secondary and tertiary education increasingly incorporate discrete mathematics, combinatorics plays a key role in encouraging learners to observe patterns, form conjectures, and understand the underlying structure of problems,



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rather than merely performing arithmetic computations (Lockwood, Caughman, et al., 2020). Thus, it helps foster an appreciation for the elegance and utility of mathematics beyond simple calculation.

The development of combinatorial reasoning in students requires more than just the mastery of algorithmic procedures (Sandefur et al., 2022). It involves guiding students to approach complex problems by breaking them down into manageable counting subproblems (English, 2005). For instance, students must learn to identify situations where the order of selection or arrangement matters, as well as when it does not. Such distinctions are vital for understanding the application of the sum and product rules, permutations, and combinations (Rezaie & Gooya, 2011). Research in mathematics education emphasizes the importance of early exposure to simple combinatorial problems, such as determining the number of possible outcomes in simple scenarios like flipping coins or arranging a few objects (Lockwood & Gibson, 2016). These introductory tasks serve as a foundation for more advanced combinatorial reasoning and foster cognitive flexibility when tackling more complex problems in higher education.

Curricular frameworks in mathematics often place combinatorics alongside other key concepts such as graph theory, set theory, and introductory probability (Sandefur et al., 2022). This positioning underscores combinatorics' importance in disciplines such as computer science, statistics, and operations research, where it provides essential tools for solving real-world problems (Levy et al., 2024). However, many educational programs still focus on the application of combinatorial formulas rather than the underlying theoretical justifications (Fitriawan et al., 2023). As a result, students may become proficient at applying formulas to obtain correct answers, but they often lack a deep understanding of why particular methods work or when to apply them in new situations. This highlights the need for an approach to teaching combinatorics that encourages both procedural fluency and conceptual understanding.

One of the main challenges in teaching combinatorics is that traditional worksheets tend to prioritize obtaining the correct answers rather than developing a deeper understanding of the underlying principles (Aini & Suryowati, 2024). This approach may lead students to calculate the correct number of outcomes without fully grasping the reasoning behind their computations (Salavatinejad et al., 2021; Uripno et al., 2023). In contrast, worksheets that embed combinatorial tasks in real-life contexts, such as organizing seating arrangements at a conference or forming committees from a larger pool, encourage students to articulate their assumptions, define variables, and justify each step of the problem-solving process (Coenen et al., 2018; Lockwood & Reed, 2018). By situating problems in relatable contexts, these tasks not only transform rote counting exercises into opportunities for rigorous proof construction, but also allow students to reflect on their thought processes, thereby

strengthening their conceptual understanding and improving their ability to explain and justify their mathematical reasoning (Trinanda et al., 2024).

The contextual worksheet reimagines traditional counting exercises by embedding combinatorial tasks within authentic, meaningful scenarios. (Rusdiana et al., 2023; Sandefur et al., 2022; Sari et al., 2023) Rather than presenting abstract problems in isolation, a contextual worksheet might frame a question around organizing seating at a conference table, selecting committee members, or designing color-coding schemes for event badges (Chavarría-Arroyo & Albanese, 2022). Such real-world contexts serve as cognitive anchors, prompting students to draw on everyday experiences as they construct and justify each combinatorial step. By situating counting problems within familiar settings, contextual worksheets encourage learners to articulate assumptions, define variables, and systematically derive solutions, thus revealing their proofing processes and deepening conceptual understanding.

This approach differs from the discovery worksheet model found in earlier studies, which typically offers open-ended tasks intended to stimulate exploration and idea generation without structured guidance (Fitriya & Permatasari, 2022; Wonda, 2023). While discovery worksheets excel at fostering creativity and self-directed inquiry, they may not reliably elicit detailed proofs of specific counting principles (Aini & Suryowati, 2024). In contrast, contextual worksheets strike a balance between guided inquiry and structured proof writing: they provide clear, scenario-based prompts that focus attention on particular combinatorial rules while still inviting students to reason critically and justify each step (Ramadhona & Perdana, 2022). By highlighting the application of counting principles within contextually rich problems, this research seeks to illuminate how contextual worksheets can more effectively reveal students' combinatorial thinking and proofing abilities.

Contextualizing combinatorial tasks within authentic real-world scenarios strengthens students' combinatorial reasoning and supports coherent argumentation in proofs (Tangkawsakul et al., 2020). Examples include counting choices embedded in sports-day modelling, and combinatorics learning designed under Realistic Mathematics Education (RME) frameworks that anchor abstract ideas in lived experience and culture (Fitriawan et al., 2023). Ethnomathematical contexts can boost Indonesian students' problem-solving engagement by linking mathematics to cultural practices (Fauzi et al., 2022). In proof contexts, contextualized tasks yield more coherent argumentative structures and clarify distinctions between axiomatic reasoning and informal explanations (Lockwood, Caughman, et al., 2020). Nevertheless, systematic tracing of the trajectory from situational constraints to formal counting formulas in combinatorics remains limited; theoretical and contextual task-design work advocates studying this transition and related teacher reflections on context-based design (Dhungana, 2023; Radmehr, 2023).

The present study aims to determine how contextual worksheets illuminate students' combinatorial thinking and proofing abilities by embedding multiplication principle, permutation, and combination tasks within authentic scenarios. Real-world

contexts, such as scheduling time slots or choosing outfits, have been shown to elicit recognition and application of combinatorial strategies within contextual tasks (Hidayati et al., 2020). Analyses of learners' written reasoning can focus on how variables are defined, assumptions stated, and the logical progression from context to formula, which is consistent with structured approaches to diagnostic reasoning and situated cognition (Maylisa et al., 2020). Contextual framing also helps reveal misconceptions (e.g., confusing ordered versus unordered selections) and supports developing more sophisticated proof strategies, a finding echoed in the literature on combinatorial reasoning. By comparing work across multiple contextual tasks, researchers can construct a diagnostic framework for assessing depth and clarity of combinatorial reasoning in proof settings.

### Research Methods

This qualitative research aims to explore how contextual worksheets reveal students' combinatorial thinking and proofing strategies in counting rules (Tressyalina et al., 2023). Employing a descriptive approach, the study analyzes naturally occurring artifacts, students' completed worksheets, and follow-up verbal protocols without manipulating instructional conditions (Cohen et al., 2007; Uripno et al., 2023; Zunaiedy et al., 2019). By situating tasks within realistic scenarios, the research focuses on understanding and characterizing the variety of proof strategies that learners employ when applying the multiplication and addition principles to proof the combinatorial problems.

Undergraduate students enrolled in a Discrete Mathematics course at a university in a regency of an Indonesian province participated in the study. All participants had previously completed the contextual worksheet on counting rules, which was developed and refined in earlier research. Selection prioritized heterogeneity in academic performance and prior experience with combinatorics to capture a broad spectrum of reasoning approaches. Participation was voluntary, with informed consent obtained in accordance with institutional guidelines (Rosser et al., 2021).

Data sources comprised the contextual worksheets and semi-structured verbal protocols. The worksheet focuses on teaching discrete mathematics concepts related to combinations and permutations. It guides students through discovery sessions where they explore counting problems involving arranging people in seats, such as determining the number of ways friends can sit in a row of seats when given a fixed number of tickets. The worksheet employs multiplication and addition rules along with factorial notation to calculate permutations (arranging  $k$  objects from  $n$  distinct objects without repetition) and combinations (choosing  $k$  objects from  $n$  distinct objects without regard to order). Through problem-solving steps and tables, learners practice computing seating arrangements for various values of  $n$  and  $k$ , ultimately deriving general formulas for permutations and combinations to apply in real-world

counting problems. This method promotes understanding of foundational counting principles via interactive questions and structured exercises. To enrich interpretation, small groups of volunteer students engaged in brief follow-up discussions, during which they articulated their reasoning and clarified ambiguous proof steps.

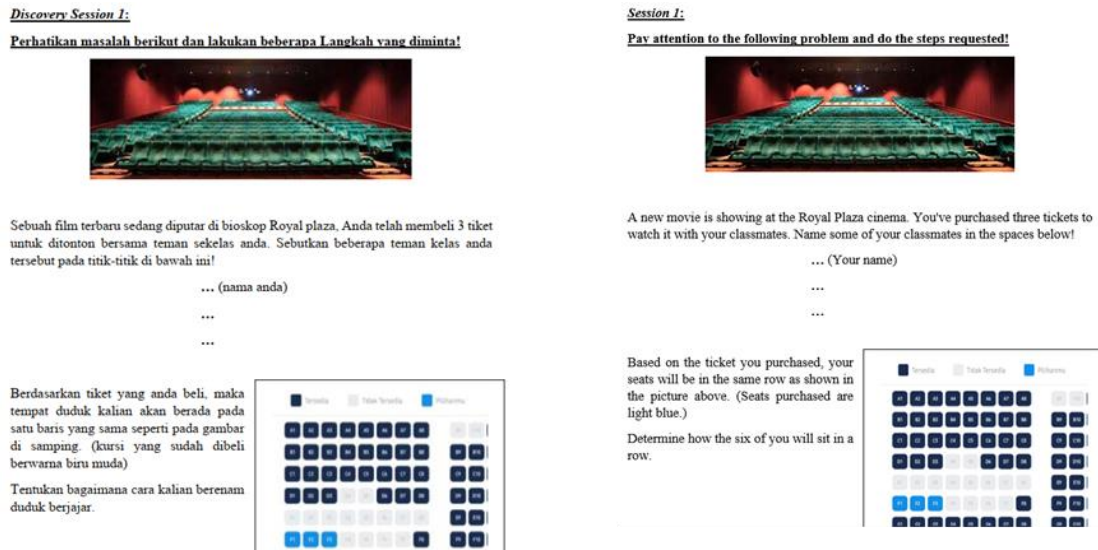


Figure 1. Indonesian and English version of worksheet

Data analysis followed an iterative, thematic coding procedure (Siswono, 2019). First, each worksheet response was examined to identify the counting rule. Next, proof strategies were classified by representational mode. Researchers noted recurring errors or omissions to pinpoint conceptual bottlenecks. Verbal protocol transcripts were triangulated with written artifacts to validate coding of incomplete or abbreviated proofs. Analytic memos captured emerging themes in combinatorial reasoning and the influence of contextual framing on proof clarity and rigor. The final output is a thematic map illustrating diverse proofing approaches among students using the contextual worksheet (Tasni et al., 2018).

## Results and Discussions

Participants A, B, and C each completed the four combinatorial tasks set within a cinema-seating context, demonstrating distinct engagement and reasoning profiles. Participant B consistently worked most rapidly and extended tasks by exploring “what-if” variations, reflecting slightly higher verbal reasoning skills than peers. Participant A showed steady, methodical progress, adhering closely to the provided worksheet prompts. Participant C, who exhibited lower word-processing fluency, required more time to interpret scenario descriptions but leveraged visual supports to scaffold understanding and maintain motivation, such as coloring seat diagrams.

All participants successfully arrived at correct numerical answers and underlying formulas for arrangements and selections. Participant B often articulated concise justifications for the permutation ( $P(n, k)$ ) and combination ( $C(n, k)$ ) formulas,

while Participant A provided thorough, step-by-step enumeration. Participant C transitioned from concrete listing of outcomes to symbolic notation after guided prompts, frequently remarking, “Coloring the seats helped me see why order matters”, illustrating how contextual visualization reinforced abstract reasoning. A comparison of completion times and reasoning approaches highlights how individual differences in verbal fluency and pattern recognition influence strategy choice and task pacing in combinatorial problem solving.

*Proof Strategies and Mathematical Reasoning*

Based on proof strategies and mathematical reasoning, Participants deployed diverse representational approaches to handle counting tasks and offered varying depths of mathematical justification when transitioning from concrete enumeration to abstract formulas.

1. *Representational Approaches*

Each participant first enumerated outcomes using familiar, concrete media before moving to symbolic notation:

No.	F1	F2	F3
1	Mei	Avita	Mira
2	Mira	Avita	Mei
3	Avita	Mei	Mira
4	Avita	Mira	Mei
5	Mira	Mei	Avita
6	Mira	Avita	Mei

**Figure 2.** Participant A outcomes Table

- *Tables and Systematic Enumeration:* All three constructed listing tables that organized seat-number combinations. Participant A created a two-column table with “Seat Order” and “Outcome Count”, manually ticking off each arrangement. Participant B extended this by color-coding rows to highlight patterns (“I see every third row shares the same first seat”, B noted). Participant C drew a basic grid, labeling axes with friend names on the horizontal axis and seat positions on the vertical, then filling cells sequentially.
- *Diagram-Based Reasoning:* Participants A and C sketched simplified seat-maps. Participant A used a linear diagram of three chairs, annotating arrows to indicate selection order. Participant C produced a tree diagram for the first two sessions, verbally justifying each branch: “This branch shows Mary then John; this one is John then Mary”. Participant B bypassed physical sketches, instead mentally visualizing “boxes” and narrating, “Box 1 picks the first friend, box 2 picks the next” a position box model that directly mapped to  $P(n, k)$ .

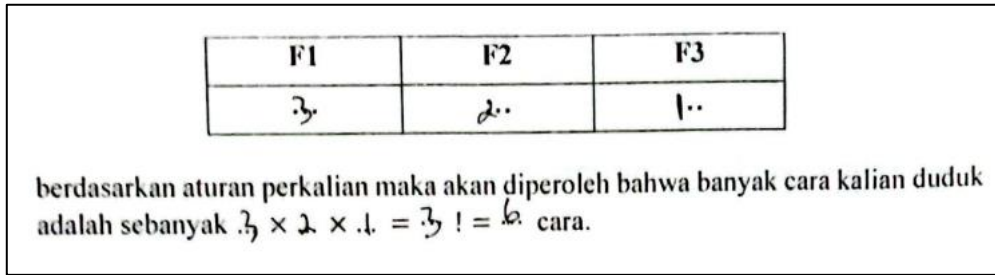


Figure 3. Participant C expresses formula of multiplication rule

- *Formula Manipulation and Algebraic Proofs:* All participants ultimately articulated the factorial formula for permutations:  $P(n, k) = \frac{n!}{(n-k)!}$ . Participant B derived this by simplifying the product  $n \times (n - 1) \times \dots \times (n - k + 1)$  and noting its equivalence to the factorial ratio. Participant A transcribed the same product sequence and boxed the cancellation of trailing factors. Participant C, after plotting two or three concrete examples, received prompting—“How would you generalize what you just counted?”—and then wrote the formula, remarking, “Oh, it’s like removing chairs after each pick”.

Berdasarkan aturan perkalian, maka diperoleh

$$\begin{aligned}
 & n \times (n - 1) \times (n - 2) \times (n - 3) \times \dots \times (n - k + 2) \times (\dots \dots \dots) \\
 &= n \times (n - 1) \times (n - 2) \times (n - 3) \times \dots \times (n - k + 2) \times \frac{(n - k)!}{(n - k)!} \\
 &= \frac{n \times (n - 1) \times (n - 2) \times \dots \times (n - k + 1) \times \dots \times 2 \times 1}{(n - k)!} \\
 &= \frac{n!}{(n - k)!}
 \end{aligned}$$

Figure 4. Participant B algebraic manipulation to generalize the formula

- *Transition from Concrete to Abstract Representation:* Participant C displayed the most pronounced shift, moving from color-filled seat diagrams to the  $P(n, k)$  ratio only after guided questioning. Participant B smoothly shifted between mental enumeration and algebraic expression, often verbalizing “Let’s generalize” immediately after listing outcomes. Participant A followed a mid-path approach: first listing outcomes, then rewriting the product sequence, and finally expressing the factorial ratio in formal notation.

*Proof of Mathematical Justification*

Participants varied in their ability to articulate the underlying principles of their strategies:

- *Explanation of Reasoning Steps:* Participant B provided succinct, logical justifications, such as “Each choice reduces available options by one, so we multiply descending numbers”. Participant A narrated each enumeration step (“I have 3 choices for seat

1, then 2 for seat 2...”), linking it to the multiplication principle. Participant C’s justification was primarily concrete (“We cross out names as we choose them”) until prompted to articulate the general rule, after which C stated, “Multiplying counts because each new pick depends on the previous one”.

- *Connection Between Multiplication Principle and Counting Outcomes:* All participants invoked the basic counting principle. Participant A explicitly wrote: “By rule of product, total outcomes = choices for seat 1 × choices for seat 2 × ...” Participant B advanced this to the generalized  $P(n, k)$  formula without intermediate listing in later sessions. Participant C, once prompted, recognized the iterative nature of choices and recast it as the factorial-ratio definition.
- *Quality of Mathematical Arguments in Contextual Settings:* The strength of justification correlated with verbal fluency. Participant B’s arguments were concise and generalized across contexts, e.g., “Whether it’s cinema seats or book order, the principle holds”. Participant A’s arguments, while thorough, remained tied to the specific ticketing scenario. Participant C’s arguments were initially narrative but evolved into correct abstract justification after scaffolded support, evidencing conceptual understanding despite lower initial articulatory clarity.

Overall, the three participants demonstrated a spectrum of representational strategies and justification quality, from concrete enumeration to formal factorial proofs, reflecting individual differences in abstraction and verbal explanation skills.

#### *Error Analysis and Misconceptions*

The distinction between permutations and combinations presented conceptual challenges for all participants, particularly during the transition from concrete enumeration to abstract formula use. Participant C showed the most pronounced difficulty distinguishing when order matters. During the fourth session, when asked about selecting versus arranging students for seats, C initially responded: “Isn't choosing and arranging the same thing? We still have the same people”. Only after guided questioning, “Does it matter if John sits in seat 1 versus seat 3?”, did C recognize the importance of positional order in permutations. Participant A demonstrated solid understanding of the multiplication principle but initially conflated permutation and combination formulas. A wrote the combination formula as  $C(n, k) = n! / (n - k)!$  before self-correcting to  $C(n, k) = n! / [(n - k)! k!]$ , stating: “Wait, I think I'm missing something in the denominator”. Participant B grasped the conceptual distinction quickly but verbally expressed uncertainty about practical applications: “I understand the math, but when would we actually use combinations versus permutations in real life?” This suggests strong procedural knowledge but weaker contextual reasoning about when each concept applies.

All participants required scaffolded support to transition from concrete enumeration strategies (listing all possible arrangements) to symbolic formula application. Participant C particularly benefited from visual supports, remarking: "The colored seat diagrams helped me see why ABC is different from CBA, but choosing ABC versus CBA gives the same group". This highlights how concrete visual representations scaffolded abstract understanding of the order-matters distinction.

#### *Implications for Contextual Worksheet Design*

The cinema-themed worksheet's progression from arranging three tickets to distinguishing permutations and combinations proved highly effective in guiding learners from concrete enumeration toward abstract factorial reasoning. Across the four sessions, participants exhibited increasingly sophisticated use of symbolic notation: Participant B began generalizing  $P(n,k)$  by Session 2, Participant A steadily translated product sequences into factorial ratios, and Participant C ultimately articulated the permutation formula after engaging with visual seat diagrams. The contextual narrative maintained sustained engagement, as reflected in remarks such as "Coloring the seats helped me see why order matters" (Participant C).

Qualitatively, the scaffolded increases in task complexity fostered conceptual growth. Initial enumeration activities-built confidence in counting outcomes, while subsequent prompts encouraged abstraction and formula derivation. Dual representations including tables, diagrams, and algebraic expressions, allowed participants to connect concrete scenarios with formal notation. Even learners with lower verbal fluency successfully transitioned to symbolic reasoning when supported by visual aids, demonstrating the value of contextually rich, multi-modal worksheets. Based on pedagogical design perspective, these findings suggest that embedding real-world narratives and progressively reducing concrete supports can effectively cultivate higher-order combinatorial thinking across diverse learner profiles.

The present study demonstrates that contextual worksheets significantly enhance students' transition from concrete enumeration to abstract combinatorial reasoning by embedding counting tasks within authentic scenarios. Participants exhibited a spectrum of representational strategies from tabular enumeration to tree diagrams and algebraic proofs highlighting how multiple representational approaches facilitate conceptual understanding. These findings align with prior research showing that contextual framing aids proof construction and deepens mathematical reasoning (Lockwood, Caughman, et al., 2020).

Participant C's marked shift from color-coded seat diagrams to formal  $P(n,k)$  notation underscores the power of visual scaffolding in bridging concrete and abstract representations. This supports the assertion that real-world contexts serve as cognitive anchors, prompting learners to articulate assumptions and systematically derive solutions (Coenen et al., 2018; Rusdiana et al., 2023). Similarly, the rapid generalization exhibited by Participant B corroborates Sandefur et al. (2022) finding that early exposure to context-rich tasks accelerates procedural fluency and fosters abstraction.

The variance in proof strategies among participants reflects individual differences in verbal fluency and pattern recognition. Participant A's thorough, step-by-step enumeration parallels Fitriawan et al. (2023) observation that learners with stronger procedural knowledge benefit from progressive reduction of concrete supports. In contrast, Participant C required guided prompts to articulate the multiplication principle, echoing Salavatinejad et al. (2021) emphasis on scaffolded questioning to elicit deeper conceptual insights. This suggests that contextual worksheets must incorporate adjustable scaffolds such as prompts for generalization or visual aids to accommodate diverse learner profiles.

Misconceptions around the order-matters distinction emerged predominantly during the combination task, with several participants initially conflating permutations and combinations. This aligns with Uripno et al. (2023) findings that students often misunderstand when to apply  $P(n,k)$  versus  $C(n,k)$ . The contextual narrative by explicitly framing seating arrangements versus group selections helped clarify these distinctions, supporting the efficacy of scenario-based contrasts in reinforcing conceptual boundaries.

From a design perspective, the cinema-themed worksheet proved effective in sustaining engagement and driving conceptual growth. The progression from concrete enumeration to symbolic proof mirrors English (2005) recommended approach of breaking complex problems into manageable subproblems. Embedding tasks in relatable contexts not only fosters procedural fluency but also cultivates the ability to justify and generalize counting principles a key aspect of advanced combinatorial reasoning (Trinanda et al., 2024).

While the qualitative insights are robust, the small participant pool limits generalizability. Future studies should examine larger cohorts and incorporate quantitative measures of learning gains to validate these findings. Additionally, exploring ethnomathematical contexts as Fauzi et al. (2022) suggest may further enhance engagement by linking combinatorics to cultural practices. Finally, longitudinal research could assess whether the benefits of contextual worksheets persist over time and transfer to novel combinatorial problems. In sum, this study reinforces the value of contextually rich, scaffolded worksheets in fostering deeper combinatorial thinking and proofing strategies. By bridging concrete scenarios and abstract formalism, educators can better cultivate students' conceptual understanding and reasoning skills in discrete mathematics.

## Conclusions and Suggestions

Contextualized worksheets grounded in real-world scenarios such as cinema seating arrangements have demonstrated remarkable effectiveness in guiding students from concrete enumeration tasks to sophisticated combinatorial reasoning. By framing counting problems within familiar narratives by imagining the placement of friends in specific rows or considering ticket combinations for movie showtimes,

learners could visualize abstract concepts through lived experiences. Tables of seat labels, color-highlighted diagrams of seating plans, and branching diagrams that mapped each decision step all provided multiple avenues for comprehension, ensuring that students with diverse learning preferences could find an accessible entry point. As supports were gradually withdrawn, students transitioned from relying on concrete representations to formulating symbolic expressions involving factorials and binomial coefficients, illustrating their growing confidence in abstract mathematical reasoning.

Through this structured approach, participants not only mastered the procedural rules governing permutations and combinations but also developed a deeper conceptual understanding of why those rules hold true. They learned to articulate assumptions, such as whether order matters in a given context, and to define variables explicitly, distinguishing between scenarios that require ordered arrangements and those that involve simple selections. The iterative practice of moving from concrete listing to pictorial models and finally to algebraic proof fostered an appreciation for the logical foundations of counting rules and helped dispel common misconceptions, such as confusing the sum and product rules or misapplying factorial notation.

Building on these qualitative insights, future studies could employ larger-scale quantitative research designs to measure the impact of contextual worksheets on students' learning gains, long-term retention, and ability to transfer combinatorial reasoning to novel problems. Investigations that incorporate culturally relevant contexts, such as traditional games, local festivals, or community events, may further enrich student engagement and reveal how familiar narratives enhance conceptual depth. Longitudinal research following the same cohort over multiple semesters would shed light on the durability of these learning benefits and their influence on subsequent topics in discrete mathematics. Additionally, comparative studies examining contextualized instruction against discovery-based and traditional worksheet approaches could help identify the most effective scaffolding strategies for learners with different backgrounds and proficiencies.

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