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Integrating 3D Technology into Garment Pattern-Making: Effects on Learning Outcomes

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Abstract

Purpose: This study examines the effects of integrating 3D technology into garment pattern-making education within a vocational education context. **Research design, data and methodology:** A quasi-experimental design was implemented with 88 first-year students in China, divided equally into a Style3D-assisted experimental group and a control group taught through traditional methods. Both groups completed identical instructional content, while learning outcomes were measured through standardized academic tests, a spatial visualization assessment, and a post-intervention engagement survey. **Results:** Findings indicate that the experimental group achieved significantly higher scores in applying knowledge, analyzing garment structures, and developing Apparel Spatial Visualization Skills, whereas no significant differences were observed in remembering or understanding. Qualitative reflections further revealed stronger engagement among experimental group students, including higher motivation, sustained focus, and improved conceptual clarity. These results demonstrate that 3D-assisted instruction is particularly effective for fostering higher-order cognitive skills and spatial reasoning, while traditional approaches remain important for reinforcing foundational knowledge. **Conclusions:** The study highlights the pedagogical value of blended instruction that combines digital simulation with manual drafting. Such integration supports both technical skill development and conceptual understanding, preparing vocational learners for the digital transformation of the fashion industry.

Keywords: Garment Pattern-Making, vocational education, spatial visualization, Style3D, learning outcomes

JEL Classification Code: I21, I23, O33, L67, C93

1. Introduction

The global apparel industry continues to be a vital contributor to economic development while simultaneously undergoing rapid digital transformation. This transformation is driven by the rising demand for sustainability, product personalization, and smart manufacturing practices. Among emerging innovations, 3D virtual prototyping technologies have gained prominence for their ability to enhance design precision, reduce fabric waste, accelerate production cycles, and improve workflow efficiency (Morandi & Tonelli, 2023).

In educational contexts, such technologies—particularly Style3D—offer new opportunities to reshape traditional garment pattern-making instruction. By allowing students to draft patterns digitally, simulate garment assembly in real time, and visualize the transformation from 2D flat patterns into 3D forms, Style3D strengthens spatial reasoning, a skill often underdeveloped in conventional manual drafting approaches (Zhu et al., 2022). These features align with constructivist and experiential learning theories, which emphasize active, hands-on exploration and iterative practice in building knowledge and technical mastery (Gül et al., 2012; Kolb, 2014).

However, despite these advantages, the integration of 3D technology into vocational education (career-oriented

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education that equips learners with occupation-specific skills) remains limited. Many vocational and technical programs still rely heavily on static diagrams, lectures, or manual drafting, leaving students proficient in procedural tasks but struggling with abstract conceptualization and spatial visualization. This problem is particularly pressing in Chinese vocational colleges, where training must balance foundational craftsmanship with the digital competencies demanded by industry.

Style3D, developed by Lingdi Digital Technology in China, provides both industrial and educational functions, including real-time garment simulation, automatic bill-of-material generation, and workflow integration. Its dual relevance highlights the potential for bridging the gap between classroom instruction and workplace requirements. Yet, current research has tended to emphasize technical functionality or student satisfaction, while neglecting the cognitive and pedagogical impacts of 3D-assisted learning (Habib & Alam, 2023).

Research Problem:

There remains insufficient empirical evidence on how 3D garment simulation technologies influence higher-order learning outcomes, spatial reasoning, and engagement in vocational education. Addressing this gap is essential to determine how such tools can prepare students for industry expectations in an increasingly digital fashion sector.

Research Objectives:

This study investigates the pedagogical value of integrating Style3D into garment pattern-making instruction within Chinese vocational education. Specifically, it aims to:

1. Evaluate the impact of 3D-integrated instruction on students' academic performance across four cognitive domains: remembering, understanding, applying, and analyzing.

2. Assess the effect of 3D visualization tools on students' Apparel Spatial Visualization Skills (ASVS)—a core competency in interpreting and constructing garments from 2D technical patterns.

3. Explore students' engagement and motivation in digitally supported learning environments, with emphasis on behavioral, emotional, and cognitive dimensions of participation.

By pursuing these objectives, the study contributes to the advancement of vocational education as a form of career-oriented training, demonstrating how immersive 3D technologies can enhance both conceptual understanding and practical skill, while aligning classroom learning with industry needs.

2. Literature Review

Compared with prior studies that focus mainly on software functionality or industry application, fewer works investigate the deeper cognitive and educational effects of 3D tools in vocational contexts. Habib and Alam (2023), for example, emphasize the need to examine higher-order thinking and spatial reasoning rather than only reporting productivity or satisfaction outcomes. This study builds on such calls by assessing Style3D's role not only in technical training but also in the development of cognitive learning outcomes.

2.1 Educational and Technological Context

The emergence of 3D digital tools such as CLO 3D, Browzwear, and Style3D has transformed the possibilities of garment visualization and pattern development in fashion education. These platforms provide realtime garment simulation, virtual fitting, and digital sewing, allowing learners to interactively observe structural design, fabric behavior, and construction logic (Pietroni et al., 2022). In addition to enhancing design precision and minimizing construction errors, 3D tools contribute to sustainable practices by reducing the need for physical samples and fabric waste.

From a learner engagement perspective, interactive digital environments support autonomy, motivation, and participation—especially among Generation Z students, who are familiar with visual and selfdirected learning modalities (Ho et al., 2019; Lee, 2022). However, the integration of such technologies requires thoughtful instructional design. Eckerson and Zhao (2018) caution that without pedagogical scaffolding, digital tools may increase extraneous mental effort. This aligns with Sweller et al. (2011), which emphasizes the importance of reducing cognitive overload during complex learning tasks.

Although the global fashion industry has widely embraced 3D modeling technologies, their pedagogical application within Chinese vocational colleges remains relatively under-researched. Existing literature often focuses on software features or productivity outcomes rather than cognitive development. As noted by Habib and Alam (2023), there is a need for empirical research exploring how 3D tools influence higher-order thinking, analytical ability, and spatial reasoning. **Compared with these prior studies, the present work goes further by examining not only technical efficiency but also the cognitive, motivational, and spatial outcomes of 3D-assisted instruction in vocational education, thereby contributing broader insights to academic discussions of digital pedagogy.

2.2 Theoretical Framework

The pedagogical foundation of this study is based on Constructivist Learning Theory, which views learning as an active, contextualized process in which knowledge is constructed through experience (Gül et al., 2012). Digital environments like Style3D enable learners to explore garment structures handson through virtual interactions, supporting the creation of meaningful connections between theory and practice. This approach is further supported by Kolb's Experiential Learning Theory, which emphasizes learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 2014).

To evaluate cognitive learning outcomes, the study adopts Anderson and Krathwohl's (2001) revision of Bloom's Taxonomy, which includes four core domains: remembering, understanding, applying, and analyzing. Each domain is aligned with specific competencies in patternmaking instruction:

Remembering: Recalling terminology, tools, and garment classifications, assessed via fillintheblank items.

Understanding: Demonstrating comprehension through glossary explanations or short written responses.

Applying: Using acquired knowledge to explain garment features, select appropriate materials, or apply digital pattern software.

Analyzing: Comparing design techniques, identifying patternmaking errors, or evaluating the structure of garments from visual cues.

2.3 Relevance of 3D Technology to Student Development

Digital tools play a significant role in enhancing students' Apparel Spatial Visualization Skills (ASVS), which refer to the ability to mentally rotate, manipulate, and interpret the spatial structure of garments based on 2D patterns (Smith et al., 2020). Platforms like Style3D allow learners to see how flat pattern pieces transform into 3D garments, providing immediate visual feedback on seam alignment, silhouette balance, and design modifications. These interactive features improve students' technical fluency and conceptual understanding of garment construction.

To evaluate ASVS development, the study employs the Digital Apparel Spatial Visualization Test (DASVT), a disciplinespecific assessment tool developed to measure apparel students' spatial abilities. The test presents 2D pattern diagrams alongside animated 3D garment models, prompting learners to select the correct visual match. It has demonstrated validity in capturing students' spatial cognition within apparelbased contexts and is particularly useful for tracking improvements following instruction with 3D tools (Smith et al., 2020).Unlike studies that focus mainly on validating measurement tools, this research connects Apparel Spatial Visualization Skills directly with academic performance, expanding the scope of analysis and offering evidence relevant to both educational research and applied fashion training.

2.4 Student Engagement

Student engagement is understood as a multidimensional construct encompassing cognitive, behavioral, and emotional domains (Fredricks et al., 2004). Cognitive engagement involves mental effort, strategic thinking, and deep processing—all of which are encouraged by the interactive and iterative nature of 3D design tasks.Behavioral engagement is reflected in active participation, attention, and timeontask, while emotional engagement captures interest, enjoyment, and satisfaction in learning.

3Dintegrated instruction has shown potential to enhance all three engagement dimensions by offering visually stimulating, challengebased learning environments. In this study, openended questionnaires and semistructured interviews were used to gather students' reflections on their experiences. These instruments helped reveal how the integration of 3D tools influenced their learning motivation, sense of achievement, and interaction with content.

2.5 Population and Context

The study is situated within a vocational college in Anhui Province, China, focusing on firstyear students enrolled in a fashion design program. These learners, aged 18-19, their comparable academic backgrounds and skill levels make them an appropriate sample for evaluating the differential impact of instructional strategies. With the fashion industry increasingly adopting digital design platforms, early exposure to 3D technologies equips these students with relevant competencies for future employment (Conlon & Gallery, 2024).

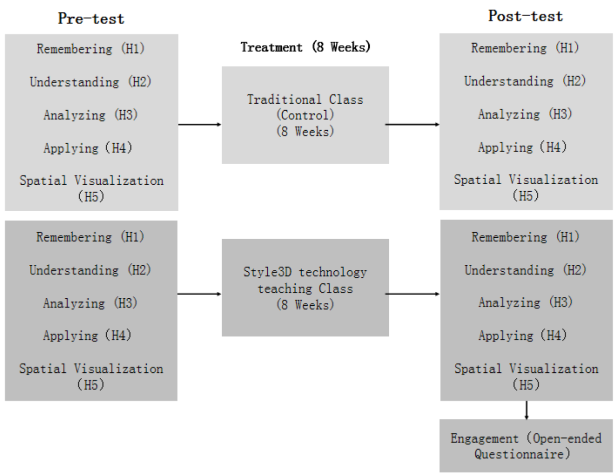

Figure 1: Conceptual Framework

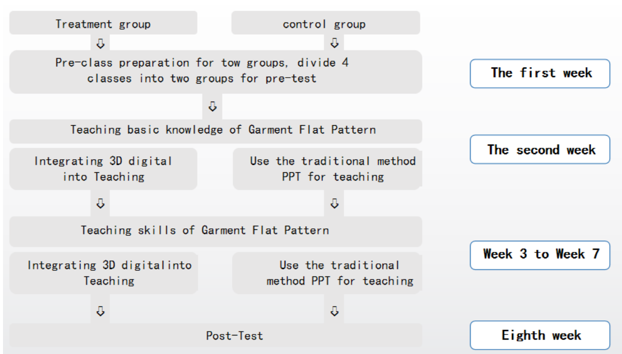

Figure 2: Instructional Comparison Diagram

2.6 Hypotheses Development

Building on the literature and theoretical framework, the study proposes the following null hypotheses:

H01: There is no significant difference in remembering performance between the experimental and control groups.

H02: There is no significant difference in understanding performance between the groups.

H03: There is no significant difference in analyzing ability.

H04: There is no significant difference in applying knowledge.

H05: There is no significant difference in Apparel Spatial Visualization Skills (ASVS).

These hypotheses guide the comparative analysis of instructional outcomes and provide a basis for evaluating the educational impact of integrating Style3D into patternmaking instruction.In doing so, the study extends beyond descriptive reports of software adoption and contributes empirical findings that strengthen theoretical understanding and inform practical innovations in vocational education research worldwide.

3. Research Methods and Materials

3.1 Research Design and Procedure

This study employed a quasi-experimental mixed-methods design, combining quantitative and qualitative evidence to evaluate the instructional value of integrating Style3D—a localized 3D garment simulation platform—into pattern-making education. Such a design is suitable in vocational classrooms where random assignment is constrained.

Two parallel first-year fashion design classes in a vocational college in Anhui Province were selected as intact groups. One class was designated the experimental group, receiving Style3D-assisted instruction, while the other served as the control group, taught via conventional PowerPoint slides and video demonstrations. Both groups covered identical course content, were taught by the same instructor, and followed synchronized lesson plans to reduce instructor and curriculum bias.

The intervention unfolded in three stages:

Preparation (Week 1): Baseline pretests were administered. The experimental group received one week of orientation in Style3D's interface and garment modeling basics, while the control group reviewed prior knowledge with the same instructor using static visuals.

Instruction (Weeks 2-7): Both groups studied garment pattern-making for eight sessions per week (45 minutes each). The control group relied on traditional diagrams and paper-based drafting demonstrations, while the experimental group engaged in real-time digital drafting, virtual stitching, and garment simulation via Style3D.

Post-intervention (Week 8): Both groups completed posttests. Additionally, the experimental group responded to open-ended questionnaires and participated in semi-structured interviews to reflect on engagement and perceived learning outcomes.

3.2 Participants and Sampling Strategy

The study population consisted of first-year vocational students enrolled in a three-year fashion design program. A purposive sampling approach was adopted, as the two classes shared comparable academic backgrounds and curriculum exposure. This method is commonly applied in intervention studies targeting specific cohorts.

A total of 88 students participated:

Experimental group: 44 students (17 males, 27 females)

Control group: 44 students (13 males, 31 females)

Both groups showed similar entrance examination scores, ensuring academic comparability. Although not randomized, the intact group design reflects the ecological reality of vocational education, providing authenticity and minimizing disruption to standard instruction.

3.3 Instruments and Measures

Three instruments were used to evaluate cognitive performance, spatial visualization, and student engagement:

Performance Tests: Both pre- and post-intervention tests were drawn from the college's standardized final examination for Garment Pattern-Making, which has been applied consistently for over a decade. The tests were designed by curriculum experts and aligned with Anderson and Krathwohl's (2001) taxonomy, covering remembering, understanding, applying, and analyzing. Each domain was scored on a 20-point rubric.

Digital Apparel Spatial Visualization Test (DASVT): Adapted from Smith et al. (2020), the DASVT included 10 items requiring learners to match flat pattern diagrams with corresponding 3D garment renderings. Previous studies confirm its validity in assessing Apparel Spatial Visualization Skills (ASVS).

Engagement Questionnaire: An open-ended six-item questionnaire, designed following Fredricks et al. (2004), assessed behavioral, emotional, and cognitive engagement. Items were reviewed by five experts in vocational pedagogy and evaluated using the Index of Item-Objective Congruence (IOC), with all items scoring above 0.75.

To enhance construct validity, all instruments were translated into Mandarin and back-translated by bilingual researchers. Pilot testing with 10 students ensured clarity of language and response accuracy.

3.4 Validity, Reliability, and Ethical Considerations

Performance Tests: Long-term institutional use, expert validation, and consistent rubrics ensured strong validity and reliability.

DASVT: Previous applications demonstrate satisfactory internal consistency and construct validity for apparel-related visualization tasks.

Engagement Questionnaire: Content validity confirmed by expert review; reliability addressed through thematic saturation and triangulation during qualitative analysis.

Ethical approval was granted by the participating institution. Informed consent was obtained from all students, who were assured of anonymity and voluntary participation. Data were stored securely, and students could withdraw at any time without consequence.

3.5 Data Collection and Analysis

3.5.1 Data were collected at three stages

Pre-intervention (Week 1): Baseline pretests were administered to both groups. The experimental group also received one week of training on Style3D to ensure familiarity with the software.

During intervention (Weeks 2-7): Observational records were kept of classroom activities, instructional interactions, and student participation.

Post-intervention (Week 8): Both groups completed posttests, and the experimental group additionally responded to an open-ended questionnaire and participated in semi-structured interviews.

All responses from the experimental group's questionnaire were collected via Wenjuanxing, a secure online survey platform that ensured anonymity and full participation.

3.5.2 Quantitative Analysis

Quantitative data were analyzed using independent-samples t-tests to compare the experimental and control groups. Descriptive statistics (mean and standard deviation) were calculated for the five measured variables: remembering, understanding, applying, analyzing, and Apparel Spatial Visualization Skills (ASVS). The t-tests were employed to determine whether differences between the two groups were statistically significant.

3.5.3 Qualitative Analysis

Open-ended questionnaire responses were analyzed using thematic analysis following six-step approach. Responses were inductively coded and then categorized into the three engagement dimensions—behavioral, emotional, and cognitive—outlined by Fredricks et al. (2004). Coding consistency was cross-validated by three independent researchers to minimize interpretive bias.

3.5.4 Hypothesis Testing

The study evaluated five alternative hypotheses:

H1: Students taught with Style3D perform significantly better in remembering than those taught traditionally.

H2: Students taught with Style3D perform significantly better in understanding than those taught traditionally.

H3: Students taught with Style3D perform significantly better in analyzing than those taught traditionally.

H4: Students taught with Style3D perform significantly better in applying knowledge than those taught traditionally.

H5: Students taught with Style3D achieve significantly higher ASVS scores than those taught traditionally.

Qualitative data were analyzed six-step thematic analysis. Responses were coded inductively and then categorized into engagement dimensions (behavioral, emotional, cognitive). Cross-checking among three independent researchers minimized interpretive bias.

4. Results and Analysis

This section presents findings from both quantitative and qualitative data collected during the quasiexperimental study. The analysis compares outcomes between the experimental group (taught with Style3D) and the control group (taught with traditional PowerPoint and video instruction), focusing on five domains: remembering, understanding, applying, analyzing, and Apparel Spatial Visualization Skills (ASVS).

4.1 Participant Profile

A total of 88 firstyear students from a vocational college in Anhui Province participated in the study. The experimental and control groups each comprised 44 students, with comparable gender distribution (experimental group: 38.6% male, 61.4% female; control group: 29.5% male, 70.5% female). Most participants were 18 years old (53.4%), and all had completed introductory coursework in fashion design and patternmaking.

Table 1 Participant Demographics

Group	Gender	Counts	% of the class	% of Total
Control	Male	13	29.5%	14.8%
	Female	31	70.5%	35.2%
Experimental	Male	17	38.6%	19.3%
	Female	27	61.4%	30.7%

4.2 Pre-Test Comparability

A pretest was administered prior to the intervention to ensure academic equivalence. Independentsamples ttests showed no significant differences between the two groups across all domains (p > 0.05), confirming that both groups started with comparable baselines.

Table 2: Independent Samples T-Test for Pre-Test Scores

Domain	t	df	p
Remembering	0.338	86	0.736
Understanding	0.151	86	0.880
Analyzing	0.126	86	0.900
Applying	0.206	86	0.838
ASVS	0.138	86	0.890

These results validate the internal comparability of the two groups before the experiment.

4.3 Post-Test Results and Learning Gains

After six weeks of instruction, post-tests were administered to assess students' learning outcomes across five domains: remembering, understanding, applying, analyzing, and Apparel Spatial Visualization Skills (ASVS). These domains were measured using two validated instruments: (a) the standardized institutional exam for the Garment Pattern-Making course, covering four cognitive levels, and (b) the Digital Apparel Spatial Visualization Test (DASVT) for ASVS.

Table 3: Descriptive Statistics for Post Test Scores

Domain	Group	Mean	SD	N
Remembering	Control	11.9	3.76	44
	Experimental	12.6	3.07	44
Understanding	Control	12.3	2.10	44
	Experimental	12.8	2.00	44
Applying	Control	9.6	1.60	44
	Experimental	10.8	1.70	44
Analyzing	Control	10.0	1.80	44
	Experimental	11.5	1.90	44
ASVS	Control	10.9	2.40	44
	Experimental	12.8	2.10	44

Table 4: Independent Samples ttest for PostTest Scores

Domain	t	df	p
Remembering	-0.932	86	0.354
Understanding	-1.272	86	0.207
Analyzing	-2.012	86	0.047
Applying	-2.268	86	0.026
ASVS	-2.393	86	0.019

Remembering: Both groups showed moderate improvement. The experimental group scored slightly higher (M = 12.6, SD = 1.8) than the control group (M = 11.9, SD = 1.9), but the difference was not statistically significant (p = 0.354).The null hypothesis was retained.

Understanding: The experimental group scored an average of 12.8 (SD = 2.0), compared to 12.3 (SD = 2.1) in the control group. Again, no significant difference was found (p = 0.207).The null hypothesis was retained.

Applying: A statistically significant difference emerged, with the experimental group scoring 10.8 (SD = 1.7) and the control group 9.6 (SD = 1.6), (p = 0.026). The visualization features in Style3D may have facilitated the application of abstract knowledge to practical contexts.The null hypothesis was rejected.

Analyzing: Students in the experimental group scored 11.5 (SD = 1.9) versus 10.0 (SD = 1.8) in the control group, a statistically significant difference (p = 0.047). This supports the hypothesis that 3D modeling aids deeper structural understanding.The null hypothesis was rejected.

Spatial Visualization Skills (ASVS)

The ASVS results, measured using a modified 10item version of the DASVT, showed the clearest performance differential. The experimental group achieved a mean score of 12.8 (SD = 2.1), while the control group scored 10.9 (SD = 2.4). This difference was statistically significant (p = 0.019), confirming the effectiveness of 3D simulation in developing spatial visualization competencies.The null hypothesis was rejected.

The results indicate that 3D-assisted instruction significantly enhanced higher-order cognitive abilities (application and analysis) and spatial visualization skills, while improvements in lower-order domains (remembering and understanding) did not reach statistical significance.

4.4 Qualitative Insights

To complement the quantitative results, qualitative data were gathered exclusively through an open-ended questionnaire administered to all students in the experimental group (N = 44) at the end of the intervention via the Wenjuanxing platform, yielding a 100% response rate. The instrument comprised six prompts targeting students' classroom experiences across behavioral, emotional, and cognitive dimensions of engagement (Fredricks et al., 2004).

A word-cloud tool was first used to surface high-frequency terms and anchor initial codes (see Figures 8-10). The analysis then followed a hybrid thematic approach, combining Coding-Reliability Thematic Analysis with Reflexive Thematic Analysis to balance coding consistency with interpretive depth. Two researchers coded independently and reconciled discrepancies before consolidating themes under the three engagement dimensions. The qualitative patterns aligned with the quantitative findings, especially in Analyzing, Applying, and ASVS, where students reported greater clarity and participation during instructor-led 3D demonstrations.

4.4.1 Behavioral Engagement

Students described stronger on-task focus and participation during 3D-enhanced sessions. Real-time transformations from 2D patterns to 3D garments improved visual intuition and sustained attention during complex explanations. Curiosity and motivation were frequently noted, alongside calls for more hands-on time to translate demonstrations into personal practice.

Illustrative excerpts:

"The live 3D transformations help me stay focused and see how pieces join."

"I'd like more time to operate the software myself."

4.4.2 Emotional Engagement

Learners reported enjoyment, satisfaction, and a sense of achievement when verifying garment structure visually in 3D. Exposure to industry-relevant tools increased motivation and perceived relevance to careers. A minority expressed frustration about limited practice opportunities, suggesting additional guided sessions would be beneficial.

Illustrative excerpts:

"Seeing my pattern 'come alive' is motivating—it feels more authentic than paper-only work."

"Sometimes I'm frustrated when I can't repeat the steps on my own."

4.4.3 Cognitive Engagement

Responses indicated enhanced spatial awareness and logical reasoning: students linked 3D changes back to flat-pattern operations, noted how line edits affected 3D fit, and adopted active strategies (note-taking, comparison, prediction). Some still found independent transfer difficult without repeated, scaffolded practice.

Illustrative excerpts:

"Watching 3D updates helps me connect each 2D change to the final fit."

"I understand during demonstrations but need more practice to do it myself."

4.4.4 Summary of Qualitative Findings

Overall, the open-ended questionnaire data indicate that 3D technology elevated behavioral focus, positive emotions, and cognitive engagement in the Garment Pattern-Making course, echoing the significant quantitative gains in Applying, Analyzing, and ASVS. At the same time, students' requests for additional structured, hands-on practice highlight the value of a balanced approach that pairs 3D demonstrations with traditional manual drafting to consolidate independent skill performance.

4.5 Summary of Hypothesis Testing

The five research hypotheses were evaluated using independent-samples t-tests. Results are summarized in Table 5.

Table 5: Hypothesis Testing Results

Hypothesis	Statement	t	p	Decision
H1	Style3D improves Remembering performance	-0.932	0.354	Not supported

Hypothesis	Statement	t	p	Decision
H2	Style3D improves Understanding performance	-1.272	0.207	Not supported
H3	Style3D improves Analyzing performance	-2.012	0.047	Supported
H4	Style3D improves Applying performance	-2.268	0.026	Supported
H5	Style3D improves Apparel Spatial Visualization Skills	-2.393	0.019	Supported

For Remembering (t = -0.932, p = 0.354) and Understanding (t = -1.272, p = 0.207), no significant differences were found; these hypotheses were not supported.

For Applying (t = -2.268, p = 0.026), Analyzing (t = -2.012, p = 0.047), and ASVS (t = -2.393, p = 0.019), the hypotheses were supported, indicating significant improvements for the experimental group.

5. Discussion, Conclusion, and Recommendation

This study investigated the pedagogical impact of integrating Style3D, a 3D garment simulation platform, into vocational fashion design education, specifically within a garment patternmaking course. The corrected results demonstrate that digitally enhanced instruction significantly improves higherorder cognitive performance and spatial visualization abilities while also fostering learner engagement. At the same time, findings highlight the continued importance of manual practice, particularly for consolidating foundational knowledge and skills.

5.1 Summary of Key Findings

The experimental group—who received instruction incorporating Style3D—significantly outperformed the control group in the cognitive domains of Analyzing and Applying, as well as in Apparel Spatial Visualization Skills (ASVS). These results indicate that 3Dassisted instruction was particularly effective in supporting advanced learning outcomes that involve structural interpretation, problemsolving, and design reasoning. The experimental group's mean score in Analyzing was 11.5 compared to 10.0 in the control group (p = 0.047), and in Applying, the scores were 10.8 versus 9.61 (p = 0.026). For ASVS, the mean score was 12.8 versus 10.9 (p = 0.019), suggesting a strong effect on students' spatial cognition.

In contrast, performance in Remembering and Understanding did not differ significantly between groups, which suggests that Style3D's benefits are more pronounced for higherlevel cognitive functions rather than for lowerorder tasks like recall or comprehension. This finding aligns with Cognitive Load Theory (Sweller et al., 2011), which suggests that multimedia tools are most effective when helping learners manage complex visualspatial information, but may not enhance rote learning.

Recent studies also support this interpretation. For example, Moritz and Youn (2022) found that 3D design platforms significantly improved students' spatial ability to transition between 2D and 3D representations, reinforcing their analytical and problemsolving skills. Similarly, Chang and Min (2022) demonstrated that spatial visualization training in apparel contexts strengthens learners' higherorder cognitive skills, even across different cultural contexts. These findings correspond well with the present study's results, confirming that 3D garment simulation enhances students' performance in application and analysis more than in memory or comprehension.

5.2 Student Engagement and Perception

The qualitative data revealed high levels of engagement among students using Style3D. Responses indicated strong behavioral, emotional, and cognitive involvement, with students noting that the interactive visuals helped them stay focused, explore garment structure dynamically, and make sense of otherwise abstract design principles.

For example, students described the ability to see garments come to life as both motivating and informative. Several noted they could better grasp the relationship between flat patterns and final garment structures. However, some students also expressed a desire for more handson experience, stating they struggled to replicate the digital process without instructor guidance.

These findings suggest that while 3D tools offer powerful visual scaffolding, they should be used in tandem with traditional practice to ensure skill retention and independence. This conclusion is consistent with Kolb's Experiential Learning Theory (2014), which emphasizes the need for both active experimentation and reflective observation. In addition, recent research confirms the motivational benefits of 3Dbased learning. Conlon and Gallery (2024) showed that students exposed to Style3D in fashion education not only developed stronger digital skills but also demonstrated greater engagement and confidence in applying them. Likewise, Lee (2022) highlighted that synchronous remote learning with 3D prototyping technologies fosters enjoyment, focus, and deeper conceptual understanding compared to traditional lecture formats.

Together, these insights reinforce that Style3D supports experiential learning by enhancing engagement and motivation, but full cognitive transfer still requires repeated manual application and structured practice.

5.3 Practical Implications for Instruction

Based on these findings, several instructional implications can be drawn:

Adopt a Blended Instructional Approach

Style3D should be integrated alongside manual drafting. While digital tools strengthen conceptual understanding and spatial reasoning, traditional practice remains essential for precision and craftsmanship.

Invest in Faculty Training

Teachers need training not only in software operation but also in designing cognitively balanced lessons that minimize overload and maximize learning effectiveness (Sweller et al., 2011).

Encourage Peer Collaboration

Students reported greater interaction during 3D sessions. Groupbased learning activities using Style3D may further enhance collaborative problemsolving—an essential competence in the fashion industry (Lee, 2022).

Ensure Equitable Access

Limited access to 3D software outside class was a common concern. Institutions should consider providing extended lab hours or student licenses to reduce disparities in exposure and practice opportunities.

5.4 Directions for Future Research

Although the current study provides empirical evidence of Style3D's effectiveness, several areas warrant further investigation:

Longitudinal Effects: Whether gains in higherorder cognition and ASVS persist over time without reinforcement.

Industry Readiness: Whether graduates trained with 3D tools demonstrate enhanced adaptability and performance in workplace settings.

Learner Differences: How prior spatial ability, gender, and learning preferences interact with digital learning environments.

Blended Models: Comparative studies on varying proportions of digital versus manual practice to optimize vocational patternmaking instruction.

5.5 Final Remarks

The integration of Style3D into garment patternmaking education significantly enhanced students′ performance in application, analysis, and spatial visualization, confirming its relevance in modern vocational training. These gains were complemented by increased engagement and improved conceptual clarity, especially in visualizing the transformation of flat patterns into 3D garments. However, the lack of impact on Remembering and Understanding underscores the necessity of a balanced instructional design.

In conclusion, 3D technologies such as Style3D should augment but not replace traditional instruction. Manual drafting, iterative practice, and reflective learning remain central to vocational skill development. As the fashion industry undergoes digital transformation, educational institutions must adapt by strategically incorporating 3D visualization tools. By doing so, they can better prepare learners with both the technical craftsmanship and digital competencies required for success in an evolving design landscape.

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