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Integrating Augmented Reality into Footwear Design Education: A Quasi-Experimental Study of Flow Experience and Learning Motivation

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Abstract

Static two-dimensional (2D) renderings are widely used in footwear design education but provide limited opportunities for interactive and spatial observation of product form. This study examined flow experience and learning motivation during augmented reality (AR)-assisted observation of novice designers' own footwear concepts. Students' 2D drawings were converted into AI-generated 3D models using Tripo3D and deployed through Artivive as image-triggered AR content. A quasi-experimental design combined a non-equivalent group comparison with a within-group repeated-measures comparison. Primary analyses included 54 second-year industrial design students (25 control; 29 experimental), with baseline artwork quality included as a covariate. The experimental group reported higher flow after AR observation than the control group after 2D observation, and the difference remained significant after ANCOVA adjustment ($F(1, 51) = 13.40$, $p < 0.001$, partial $\eta^2 = 0.208$). Within the experimental group, flow also increased from 2D to AR observation ($t(28) = 4.98$, $p < 0.001$, $dz = 0.92$). Learning motivation showed less consistent evidence: intrinsic goal orientation differed in the unadjusted comparison, but this finding was not robust after covariate adjustment, multiple-comparison correction, and reliability considerations. The findings support AR-assisted observation as an engaging supplementary design-education activity while not establishing broader motivational or learning-performance improvements.

Keywords: footwear design; augmented reality; interactive AR visualization; flow experience; design education; human–computer interaction

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1. Introduction

Augmented reality (AR) has been increasingly applied to product visualization, virtual try-on, design evaluation, and educational activities. In footwear-related applications, previous studies have demonstrated that AR can support customization, virtual fitting, and interactive evaluation of three-dimensional product representations. However, the educational use of AR raises a different question: whether an AR-supported representation can provide a meaningful observation experience for novice designers who are learning to interpret and evaluate their own design work. This study addresses this issue in an undergraduate footwear design course by examining flow experience and learning motivation following conventional two-dimensional (2D) and AR-assisted observation.

1.1. Background and Motivation

Visual representation is essential in product design education because it allows learners to express ideas, communicate intentions, and examine design features. Sketches, render-

ings, and models also serve as cognitive resources for visual reasoning, reflection, and concept development [1–5]. Observing and reinterpreting a drawing can reveal relationships that were not initially apparent, while the information learners recognize depends partly on their design experience [6,7]. These processes are relevant to footwear design, where form, proportion, color, material, and surface details must be considered together.

Hand-drawn 2D representations provide an accessible means of developing and presenting footwear concepts. However, each view presents selected features, requiring learners to infer spatial relationships that are not directly visible. Different representational formats can therefore offer complementary support for design observation [8,9]. For novice footwear designers, additional viewpoints may help them reconsider the relationship between a drawing and the intended product form.

Augmented reality (AR) extends this activity by linking content to the physical environment through a live camera view [10–12]. This should be distinguished from standalone 3D visualization: displaying or rotating a 3D model on a screen does not by itself constitute AR. In the present study, students' 2D footwear drawings were converted into 3D models using Tripo3D and deployed through Artivive, where the original drawing functioned as a trigger image for displaying the model in AR. Systematic reviews have documented the educational applications, benefits, challenges, and learning effects of AR [13–15].

Footwear-related AR applications are not new. Previous studies have addressed footwear customization [16], virtual try-on and foot tracking [17], and user experience across real, virtual-reality, and AR footwear conditions [18]. Educational studies have also examined AR in creative design teaching, technology acceptance, and usability [19–21]. These studies establish precedents, but their primary focus differs from observing students' own design work in footwear design education.

The educational value of AR also depends on learners' psychological responses. Flow theory describes focused involvement through concentration, perceived control, and enjoyment [22–24], whereas learning motivation concerns goals, task value, expectations of success, and affective responses [25,26]. These constructs provide complementary but distinct perspectives on learners' responses to AR-assisted design observation.

1.2. Research Problem

Previous research demonstrates that AR can support footwear visualization and educational activities, but the existing evidence leaves a specific instructional question unresolved. Footwear-related studies have mainly focused on customization, virtual try-on, fit-related interaction, and user experience [16–18], while educational studies have examined broader creative design teaching, technology acceptance, usability, and learning outcomes [19–21]. Comparatively little evidence addresses novice footwear designers observing their own work through AR.

Three issues therefore warrant investigation. First, design observation involves reflection and interpretation [1,4,5], and learners' recognition of meaningful visual relationships varies with experience [6,7]. Second, interactive visualization does not necessarily produce flow; flow is also associated with challenge, skill, perceived control, and learning conditions [27,28]. A meta-analysis reported no statistically significant overall effect of AR on flow [29], indicating the need for context-specific evidence. Third, learning motivation comprises distinct goals, values, expectations, and affective responses [25,26], so an engaging activity may not produce equivalent differences across motivational dimensions [30,31].

The scientific contribution of this study is therefore not the introduction of AR technology to footwear. Rather, it evaluates an image-triggered AR observation workflow in which novice designers examine representations derived from their own 2D footwear designs. The study further distinguishes immediate flow experience from multidimensional learning

motivation and combines between-group and within-group comparisons while controlling for baseline artwork quality. Because no standalone interactive 3D condition was included, observed differences are interpreted as associations with the implemented AR-assisted observation activity rather than as effects uniquely attributable to AR technology.

1.3. Research Questions

This study had two objectives: to compare reported flow experience between AR-assisted and 2D observation of students' own footwear designs, and to examine differences in learning motivation between learners exposed to the two observation conditions.

The following research questions guided the study:

RQ1. How does reported flow experience differ between AR-assisted and 2D observation of students' own footwear designs?

RQ2. How do learning motivation dimensions differ between learners exposed to AR-assisted observation and those exposed to 2D observation?

These questions focus on immediate experiential and motivational responses. They do not assume improvements in design quality or learning performance, which were not directly measured.

2. Theoretical Framework

This section establishes the theoretical basis for examining design representation, AR-assisted observation, learning motivation, and flow experience, and subsequently integrates these perspectives to develop the research hypotheses.

2.1. Design Representations and Reflective Visual Reasoning in Footwear Design Education

Design representations support idea development, communication, and evaluation by making emerging concepts visible [1–5]. Schön described designing as a reflective conversation with materials [1], while Goldschmidt emphasized the interaction between drawing and interpreting visual information [4]. Representations therefore provide resources for reasoning as well as records of design intentions.

Observing a drawing can reveal relationships that were not initially intended. Suwa et al. identified unexpected discoveries through sketch reinterpretation [5], and Suwa and Tversky showed that designers extract perceptual, spatial, and functional information from sketches [6]. Such interpretation also varies with experience. Menezes and Lawson found differences in how novice and advanced design students perceive conceptual sketches [7].

Different representational formats support different design purposes. Tovey et al. discussed sketching in concept development, while Pei et al. classified representations used throughout the design process [8,9]. In footwear design, 2D drawings communicate silhouette, proportion, color, and selected details, whereas spatial representations provide additional viewpoints and surface relationships. These formats offer complementary opportunities for observing and reconsidering a design.

2.2. AR-Based Visualization and Interaction in Design Education

AR integrates digital content with the physical environment and supports real-time interaction [10–12]. It should be distinguished from standalone 3D visualization: rotating a 3D model on a screen does not itself constitute AR. In image-triggered AR, recognized targets activate digital content overlaid within the live camera view. Educational reviews identify visualization and interaction as important affordances, alongside usability and cognitive challenges [13,14,32,33].

Product representations communicate relationships among form, structure, and surface features [8,9]. Kirpes et al. documented applications of 3D product models [34]. In footwear,

Luh et al. applied AR to customization [16], Yang et al. developed an RGB-D AR virtual try-on system for personalization and design evaluation [17], and Chu et al. compared real, VR, and AR footwear try-on experiences, including presence and usability [18]. These studies establish precedents for AR-based footwear visualization.

Educational applications address different purposes. Wei et al. examined AR-based teaching in creative design [19], Cabero-Almenara et al. examined immersive technologies in teaching art history [20], and Volioti et al. evaluated AR usability in geography education [21]. These studies support educational integration but address outcomes distinct from the present combination of flow and learning motivation.

AR outcomes also depend on instructional context. Garzón et al. identified pedagogical approach as a moderator [35], while reviews reported variation across applications [14,15,33]. Visual content, interaction, and instructional guidance should therefore be considered together.

2.3. Learning Motivation in Technology-Enhanced Design Learning

Learning motivation includes learners' goals, values, expectations, and affective responses to learning [26]. The MSLQ distinguishes intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning and performance, and test anxiety [25]. These dimensions represent different aspects of course-related motivation.

Self-determination theory explains how support for autonomy and competence can contribute to motivation [30]. Interest-development theory distinguishes situational interest from more developed individual interest [31]. An engaging activity may therefore attract immediate attention without producing equivalent changes in broader motivational beliefs.

AR research has reported motivational benefits in some educational settings [14,29], and Wei et al. examined its application in creative design teaching [19]. Lin and Yu found favorable effects on indicators including attention, relevance, confidence, satisfaction, and interest [29]. Differences in constructs and measurement approaches nevertheless require caution when comparing these findings.

Design representations allow learners to examine and reconsider their own ideas [1,4,9]. AR-assisted observation may make this process more engaging, while motivation theories distinguish immediate appeal from beliefs about course value and personal capability [25,26,30,31]. This distinction provides a basis for examining motivational responses to AR-supported design learning without assuming uniform improvement across dimensions.

2.4. Flow Experience in Interactive Learning Environments

Flow describes deep involvement in an activity. Csikszentmihalyi emphasized focused attention and an appropriate balance between perceived challenges and skills [22]. Nakamura and Csikszentmihalyi further distinguished conditions such as clear goals and feedback from experiential features including concentration and perceived control [24].

Educational research supports these concepts. Shernoff et al. associated classroom engagement with challenge, skill, relevance, and control [27]. In digital environments, Hoffman and Novak, Novak et al., and Skadberg and Kimmel examined relationships among interactivity, attention, enjoyment, and flow [23,36,37].

A recent meta-analysis linked learning flow with task, environmental, individual, and interpersonal characteristics [28]. AR-specific evidence remains mixed: Lin and Yu found no statistically significant overall effect on flow despite favorable effects on several other outcomes [29]. Interactive visualization therefore warrants investigation without ensuring that flow occurs.

Presence is related but distinct. The Igroup Presence Questionnaire conceptualizes presence through spatial presence, involvement, and experienced realism [38], and footwear AR research has examined presence as a user-experience outcome [18]. Because presence was not directly measured here, flow should not be interpreted as equivalent to immersion or spatial presence.

Flow and learning motivation also provide complementary perspectives. Motivation concerns goals, values, beliefs, and interest [25,26,30,31], whereas flow concerns involvement during an activity [22,24,27]. They should not be treated as interchangeable constructs.

2.5. Theoretical Synthesis and Research Gap

Design cognition research establishes that representations support reflection and visual reasoning, with interpretation varying by experience [1,4–7]. AR offers additional possibilities for linking digital content with physical visual contexts [10–12]. Footwear AR research has addressed customization, virtual try-on, personalization, and presence-related user experience [16–18], while educational research has examined broader design activities, technology acceptance, and usability [19–21]. Comparatively little evidence addresses novice footwear designers observing representations derived from their own work while flow and multidimensional learning motivation are evaluated separately.

Flow theory emphasizes concentration, perceived control, and sustained involvement [22,24]. Digital and educational research connects these experiences with interactivity and learning conditions [23,27,28,36,37]. The implemented AR activity combined image-triggered AR delivery with changing-perspective 3D visualization. Because no standalone interactive 3D comparison was included, any observed difference is interpreted as associated with the implemented AR-assisted activity rather than uniquely attributable to AR registration. These relationships support the hypothesis.

H1. *Flow experience is expected to be higher following AR-assisted observation than following 2D observation.*

Learning motivation reflects distinct goals, values, expectations, and affective responses [25,26]. Self-determination and interest-development theories explain how engaging activities can support motivation and stimulate interest [30,31]. AR may provide such opportunities, although its educational value depends on the activity and pedagogical approach [14,19,35]. Previous motivational findings provide grounds for proposing [29].

H2. *Learning motivation is expected to differ between learners experiencing AR-assisted observation and those experiencing 2D observation.*

Presence represents an AR-related construct [18,38] but was not measured in this study. Accordingly, the hypotheses concern reported flow and learning motivation rather than immersion, learning achievement, or design performance.

3. Materials and Methods

This section describes the quasi-experimental design, participants, AR implementation, measurement instruments, experimental procedure, and statistical analyses.

3.1. Research Design

This study employed a quasi-experimental design combining a non-equivalent between-group comparison with a within-group repeated-measures comparison. Participants were novice footwear design learners drawn from two existing course cohorts and were not

randomly assigned to conditions. Two observation modes were compared: viewing participants' own two-dimensional (2D) footwear drawings and viewing augmented reality (AR) representations derived from the same designs. Flow experience was examined through both between-group and within-group comparisons, whereas learning motivation was examined between the control and experimental cohorts.

Both groups created footwear design drawings through freehand drawing on graphics tablets. The control group observed their completed 2D drawings and subsequently completed the flow and learning motivation questionnaires. The experimental group first observed their 2D drawings and completed the flow questionnaire, followed by an AR observation activity and a second flow assessment. Learning motivation was measured after the AR activity.

The design therefore combined a between-group comparison with a within-group comparison of flow in the experimental group. Learning motivation was assessed once in each group. Baseline artwork quality was included as a covariate to account for differences in the quality of the designs available for observation.

3.2. Participants

Participants were second-year undergraduate students in the Department of Industrial Design who were enrolled in an elective footwear design course. All were learning footwear design for the first time, although they had prior experience in general design coursework. Participants recruited from existing course cohorts comprised the control and experimental groups.

The verified baseline dataset included 57 participants: 25 in the control group and 32 in the experimental group. Each participant's artwork rating was checked against the corresponding footwear drawing and linked to questionnaire responses through coded identifiers.

The primary analyses included 54 participants with complete eligible records for baseline artwork quality, flow experience, and learning motivation: 25 in the control group and 29 in the experimental group. Three experimental participants had paired flow measurements but lacked an eligible learning motivation record and were therefore excluded from the common analytical sample. A supplementary within-group analysis included all 32 experimental participants with paired flow measurements after 2D and AR observation. No missing responses were imputed.

3.3. Design Materials and AR Implementation

Participants created their own 2D footwear design drawings through freehand drawing on graphics tablets. These drawings served as the materials for the 2D observation condition and as the source images for generating the corresponding AR content. Figure 1 shows an example of a participant-created footwear drawing.



Figure 1. Example of a participant-created 2D footwear design drawing used in the 2D observation condition and as the source image for AR preparation.

For the AR condition, each 2D footwear image was uploaded to Tripo3D (Holymolly Limited; https://www.tripo3d.ai/, accessed on 10 September 2026), where the image-to-3D function generated a corresponding 3D footwear model with inferred geometry and texture. The generated model was exported in GLB (.glb) format. Tripo3D was therefore used for image-to-3D generation, whereas Artivive Bridge (Artivive GmbH, Vienna, Austria; https://www.artivive.com/, accessed on 10 September 2026) was used for AR deployment and observation. Figure 2 presents an example of the generated 3D model.



Figure 2. Example of an AI-generated 3D footwear model produced from a participant's 2D design image using Tripo3D.

The .glb model was imported into Artivive Bridge. The original 2D footwear drawing was assigned as the trigger image, and the generated model was linked as its digital 3D layer. Model position and scale were adjusted before publication.

During observation, participants scanned their original drawing using the Artivive mobile application. Once the trigger image was recognized, the corresponding 3D model was overlaid within the live camera view. Participants could observe the model from different perspectives by changing the position and angle of the mobile device. Thus, the AR condition involved image-triggered registration of the generated 3D model with the participant's original drawing rather than standalone 3D model viewing. Figure 3 provides an illustrative reconstruction of the image-triggered AR viewing configuration used in the study.



Figure 3. Illustrative reconstruction of the image-triggered AR viewing configuration, showing the original 2D drawing as the trigger image and the corresponding AI-generated 3D model as AR content.

Each observation activity lasted 60 s. Participants viewed representations derived from their own designs rather than a common stimulus. Because the 3D models were generated from single 2D images, their geometric and texture fidelity depended on the source image and the image-to-3D generation process.

3.4. Measures

The study included three main measurement components: baseline artwork quality, flow experience, and learning motivation. The following subsections describe the scoring procedures and measurement instruments used for each component.

3.4.1. Baseline Artwork Quality

Baseline artwork quality was independently assessed by three lecturers using a study-specific 1–5 rating rubric covering five aspects: form and proportion, design completeness, visual communication, detail development, and overall design performance. These aspects served as descriptors for the overall artwork rating rather than separately scored subscales. Artworks were identified by codes, and participant information was maintained separately.

For each artwork, the baseline score was calculated as the mean of the three lecturers' ratings, with higher scores indicating better artwork quality. Inter-rater reliability of the averaged ratings was evaluated using a two-way mixed-effects, absolute-agreement, average-measures intraclass correlation coefficient, ICC(A,3). This model was selected because the same three lecturers constituted the fixed rating panel and the averaged rating was used in subsequent analyses.

The baseline artwork score was used as a covariate to account for differences in the quality of the designs being observed. It was not a baseline measure of flow experience or learning motivation.

3.4.2. Flow Experience

Flow experience was assessed using a study-specific 14-item questionnaire developed with reference to flow theory and previous flow measurement research in human–computer interaction [22–24,36,37]. The questionnaire was adapted to the context of footwear design observation and addressed focused attention, perceived control, enjoyment, accomplishment, temporal experience, and direct self-reports of flow. All items were rated on a six-point response scale, with higher scores indicating stronger endorsement of the experiences described.

The control group completed the questionnaire after viewing their 2D drawings, whereas the experimental group completed it after both 2D and AR observation. The overall flow score was calculated as the mean of the 14 numbered items. An additional question assessing participants' understanding of the flow description was excluded from the score.

Internal consistency was assessed using Cronbach's alpha, and the same scoring procedure was applied across groups and observation conditions. The questionnaire assessed flow experience rather than spatial presence or immersion; these constructs were not directly measured in the present study.

3.4.3. Learning Motivation

Learning motivation was assessed using the 31-item motivation section of the Motivated Strategies for Learning Questionnaire (MSLQ) [25]. The original MSLQ uses a seven-point response format; in the present study, the response format was adapted to a six-point scale ranging from 1 (strongly disagree) to 6 (strongly agree). Similar six-point adaptations of MSLQ items have been used in previous educational research [39,40]. Because this

represented a modification of the original instrument, internal consistency was evaluated separately for each motivational dimension in the present sample.

The questionnaire comprised six dimensions: intrinsic goal orientation (four items), extrinsic goal orientation (four items), task value (six items), control of learning beliefs (four items), self-efficacy for learning and performance (eight items), and test anxiety (five items). Each dimension was scored by averaging the scores of its constituent items.

Higher scores indicated stronger endorsement of the corresponding motivational dimension. Test anxiety retained its original scoring direction, with higher scores indicating greater anxiety. The six dimensions were analyzed separately rather than combined into an overall motivation score.

Participants completed the questionnaire after their final observation activity: 2D observation in the control group and AR observation in the experimental group. Internal consistency was assessed separately for each dimension and group.

3.5. Experimental Procedure

Participants in both groups first completed a footwear design drawing through free-hand drawing on a graphics tablet. Their own completed drawings were subsequently used as the observation materials and as source images for the AR representations.

The control group observed their 2D drawings for 60 s and subsequently completed the flow and learning motivation questionnaires.

The experimental group first observed their 2D drawings for 60 s and completed the flow questionnaire. They then participated in an approximately five-minute transition involving access to the prepared Artivive content, application setup, and researcher-guided assistance. Following setup, participants scanned their original drawing and observed the corresponding AR representation for 60 s, changing the position and angle of the mobile device as desired. They then completed the flow questionnaire again and the learning motivation questionnaire.

The transition interval separated the two observation activities but included setup and researcher interaction and was therefore not treated as a validated washout period.

Although each observation period was standardized at 60 s, the experimental group experienced both observation conditions and therefore received additional exposure to their designs. The sequence was also fixed, with 2D observation preceding AR observation. These features were considered when interpreting the between-group differences and within-group changes in flow.

3.6. Data Analysis

Analyses were conducted in Python (Python Software Foundation; https://www.python.org/, accessed on 10 September 2026). Descriptive statistics included sample sizes, means, and standard deviations. All inferential tests were two-sided, with a significance threshold of 0.05. Reliability analyses included Cronbach's alpha for questionnaire measures and ICC(A,3) for the averaged baseline artwork ratings.

3.6.1. Between-Group Comparisons

Welch's independent-samples *t*-tests were used to compare the groups in terms of baseline artwork quality, flow experience, and the six learning motivation dimensions. For the flow comparison, the control group's score after 2D observation was compared with the experimental group's score after AR observation. Unadjusted mean differences, 95% confidence intervals, and Cohen's d were calculated to describe the magnitude and precision of group differences.

Analysis of covariance (ANCOVA) was then used to compare outcomes while adjusting for baseline artwork quality. ANCOVA findings were summarized using adjusted means, group effects, and partial eta squared. Covariate adjustment accounted for measured variation in artwork quality but did not eliminate potential differences between the nonrandomized cohorts.

3.6.2. Within-Group Flow Comparison

Paired-samples *t*-tests compared experimental participants' flow scores after 2D and AR observation. The primary paired comparison used the 29 experimental participants in the common analytical sample. A supplementary analysis included all 32 participants with eligible paired flow responses.

Mean changes, 95% confidence intervals, and Cohen's *dz* were calculated. Positive differences indicated higher reported flow after AR observation.

3.6.3. Model Diagnostics and Robustness Analyses

The homogeneity-of-regression-slopes assumption was examined by adding a group-by-baseline interaction to each ANCOVA model. Residual normality, variance homogeneity, and influential observations were assessed using the Shapiro–Wilk test, median-centered Levene's test, and Cook's distance, respectively. HC3 heteroscedasticity-robust standard errors were additionally calculated to assess the robustness of group inferences to unequal residual variances.

The six learning motivation dimensions formed a family of related comparisons. Holm adjustment was applied separately to the six Welch-test *p*-values and the six ANCOVA group-effect *p*-values. Both unadjusted and adjusted values were retained for transparent interpretation.

Findings were interpreted alongside effect sizes, confidence intervals, measurement reliability, and the limitations arising from the nonrandomized cohorts and fixed observation sequence.

4. Results

This section presents the baseline and reliability results, between- and within-group comparisons of flow experience, learning motivation outcomes, robustness analyses, and findings in relation to the hypotheses.

4.1. Baseline Artwork Quality and Scale Reliability

The primary analytical sample comprised 54 participants, including 25 in the control group and 29 in the experimental group. Baseline artwork quality averaged 3.50 (SD = 0.59) in the control group and 3.45 (SD = 0.62) in the experimental group. Welch's independent-samples *t*-test indicated no statistically significant difference ($t(51.34) = -0.29$, $p = 0.774$, Cohen's $d = -0.08$). The mean difference, calculated as experimental minus control, was −0.05, with a 95% confidence interval of [−0.38, 0.28]. Baseline artwork quality was therefore retained as a covariate in subsequent analyses.

Inter-rater reliability was examined across all 57 artworks rated by the same three lecturers. The averaged ratings showed satisfactory inter-rater agreement (ICC(A,3) = 0.756), supporting the use of the mean lecturer rating as the baseline artwork score.

The 14-item flow questionnaire showed high internal consistency in the control group following 2D observation ($\alpha = 0.923$) and in the experimental group following both 2D observation ($\alpha = 0.914$) and AR observation ($\alpha = 0.944$). Reliability estimates for the learning motivation dimensions varied across groups (Table 1). Intrinsic goal orientation

($\alpha = 0.501$) and test anxiety ($\alpha = 0.535$) showed relatively low internal consistency in the experimental group and were therefore interpreted cautiously.

Table 1. Internal consistency of the flow and learning motivation measures.

Measure	Control Group, α	Experimental Group, α
Flow experience	0.923	0.944
Intrinsic goal orientation	0.660	0.501
Extrinsic goal orientation	0.609	0.782
Task value	0.793	0.917
Control of learning beliefs	0.626	0.681
Self-efficacy for learning and performance	0.919	0.899
Test anxiety	0.637	0.535

Note. Control group: $n = 25$; experimental group: $n = 29$. Flow coefficients shown in the table refer to 2D observation in the control group and AR observation in the experimental group. The experimental group's flow coefficient following initial 2D observation was 0.914.

4.2. Between-Group Differences in Flow Experience

The experimental group reported higher flow after AR observation (M = 4.85, SD = 0.91) than the control group after 2D observation (M = 3.95, SD = 0.87). Welch's *t*-test indicated a statistically significant difference ($t(51.46) = 3.71$, $p < 0.001$, Cohen's $d = 1.01$). The unadjusted mean difference was 0.90, with a 95% confidence interval of [0.41, 1.39], representing a large between-group difference.

After adjustment for baseline artwork quality, the group difference remained statistically significant ($F(1, 51) = 13.40$, $p < 0.001$, partial $\eta^2 = 0.208$). The adjusted means were 3.95 for the control group and 4.85 for the experimental group, with an adjusted difference of 0.90 (95% CI [0.41, 1.40]). The between-group flow results are summarized in Table 2.

Table 2. Between-group comparison of flow experience.

Analysis	Control	Experimental	Difference	Test	*p*	Effect
Welch's *t*	3.95 (0.87)	4.85 (0.91)	0.90 [0.41, 1.39]	$t(51.46) = 3.71$	<0.001	$d = 1.01$
ANCOVA	3.95	4.85	0.90 [0.41, 1.40]	$F(1, 51) = 13.40$	<0.001	$\eta p^2 = 0.208$

Note. Values in the first row are unadjusted means (SDs); values in the second row are adjusted means evaluated at the pooled baseline artwork score of 3.47. Differences are experimental minus control. The experimental and control outcomes were measured after AR and 2D observation, respectively.

The group-by-baseline interaction was not significant ($p = 0.413$). Although the residual normality test indicated a departure from normality ($p = 0.003$), inference using HC3 heteroscedasticity-robust standard errors also showed a significant group difference ($p < 0.001$).

4.3. Within-Group Changes in Flow Experience

Among the 29 experimental participants in the primary sample, mean flow increased from 4.28 (SD = 0.85) after 2D observation to 4.85 (SD = 0.91) after AR observation. The paired-samples *t*-test indicated a significant increase, $t(28) = 4.98$, $p < 0.001$, Cohen's $d_z = 0.92$, where the paired effect size was calculated using the standard deviation of individual change scores. The mean increase was 0.56, with a 95% confidence interval of [0.33, 0.80].

The supplementary analysis of all 32 experimental participants with eligible paired flow measurements showed a similar pattern. Mean flow increased from 4.28 (SD = 0.81)

to 4.86 (SD = 0.88), $t(31) = 5.36$, $p < 0.001$. The mean increase was 0.58, 95% CI [0.36, 0.80], with a paired effect size of 0.95. The within-group flow results are summarized in Table 3.

Table 3. Within-group comparison of flow after 2D and AR observation.

Sample	*n*	2D, *M* (SD)	AR, *M* (SD)	Change [95% CI]	*t* (df)	*p*	*dz*
Primary sample	29	4.28 (0.85)	4.85 (0.91)	0.56 [0.33, 0.80]	4.98 (28)	<0.001	0.92
All eligible paired responses	32	4.28 (0.81)	4.86 (0.88)	0.58 [0.36, 0.80]	5.36 (31)	<0.001	0.95

Note. Change scores were calculated as AR minus 2D. Cohen's d_z denotes the mean change divided by the standard deviation of the change scores. The supplementary sample includes the primary sample and does not constitute an independent replication.

These comparisons indicate higher reported flow following AR observation within the implemented sequence. Because all experimental participants completed 2D observation before AR observation, the observed increase cannot be attributed exclusively to the AR condition.

4.4. Between-Group Differences in Learning Motivation

Descriptive statistics and Welch's *t*-tests for the six learning motivation dimensions are presented in Table 4. Intrinsic goal orientation was higher in the experimental group (M = 4.99, SD = 0.61) than in the control group (M = 4.52, SD = 0.64) ($t(50.01) = 2.77$, $p = 0.008$, Cohen's $d = 0.76$). The mean difference was 0.47 (95% CI [0.13, 0.81]). This comparison remained significant after Holm adjustment across the six motivation dimensions (p_Holm = 0.047).

Table 4. Descriptive statistics and Welch's tests for learning motivation.

Dimension	Control, *M* (SD)	Experimental, *M* (SD)	t (df)	*p*	Holm *p*	*d*
Intrinsic goal orientation	4.52 (0.64)	4.99 (0.61)	2.77 (50.01)	0.008	0.047	0.76
Extrinsic goal orientation	4.37 (0.75)	4.17 (1.00)	−0.82 (51.12)	0.413	1.000	−0.22
Task value	4.71 (0.52)	4.89 (0.83)	0.93 (47.70)	0.359	1.000	0.24
Control of learning beliefs	4.58 (0.69)	4.75 (0.69)	0.90 (50.76)	0.371	1.000	0.25
Self-efficacy for learning and performance	4.24 (0.86)	4.50 (0.85)	1.10 (50.76)	0.278	1.000	0.30
Test anxiety	4.41 (0.71)	4.26 (0.75)	−0.77 (51.49)	0.444	1.000	−0.21

Note. Control group: $n = 25$; experimental group: $n = 29$. Positive effect sizes indicate higher experimental-group scores. Higher test anxiety scores indicate greater anxiety. Holm adjustment was applied across the six motivation comparisons.

The remaining dimensions did not show statistically significant between-group differences. The experimental group had descriptively higher task value, control of learning beliefs, and self-efficacy and lower extrinsic goal orientation and test anxiety. Their unadjusted *p*-values ranged from 0.278 to 0.444.

After adjustment for baseline artwork quality, intrinsic goal orientation remained descriptively higher in the experimental group, with an adjusted difference of 0.46 (95% CI [0.12, 0.80], $F(1, 51) = 7.51$, unadjusted $p = 0.008$, partial $\eta^2 = 0.128$). However, the Holm-adjusted *p*-value was 0.0506 and therefore exceeded the 0.05 threshold. The corresponding HC3 analysis also did not remain significant after Holm adjustment (p_Holm = 0.062).

None of the other motivation dimensions showed statistically significant adjusted group differences. Their unadjusted ANCOVA *p*-values ranged from 0.299 to 0.483, with Holm-adjusted *p*-values of 1.000. The ANCOVA results for the six learning motivation dimensions are summarized in Table 5.

Table 5. ANCOVA results for learning motivation, controlling for baseline artwork quality.

Dimension	Control adj. M	Experimental adj. M	F(1, 51)	*p*	Holm *p*	Partial η^2
Intrinsic goal orientation	4.52	4.99	7.51	0.008	0.0506	0.128
Extrinsic goal orientation	4.37	4.17	0.71	0.404	1.000	0.014
Task value	4.72	4.88	0.71	0.403	1.000	0.014
Control of learning beliefs	4.58	4.75	0.74	0.394	1.000	0.014
Self-efficacy for learning and performance	4.25	4.49	1.10	0.299	1.000	0.021
Test anxiety	4.40	4.26	0.50	0.483	1.000	0.010

Note. Adjusted means were evaluated at the pooled baseline artwork score of 3.47. Holm adjustment was applied across the six ANCOVA group-effect tests. Confidence intervals reported in the text are pointwise intervals and were not adjusted for multiple comparisons.

The intrinsic goal-orientation result should also be interpreted in conjunction with its relatively low internal consistency in the experimental group ($\alpha = 0.501$). Accordingly, the result represents suggestive rather than robust evidence of a motivational difference.

4.5. Robustness of the Main Findings

The flow result remained statistically significant after adjustment for baseline artwork quality and when HC3 heteroscedasticity-robust standard errors were used ($p < 0.001$). The nonsignificant group-by-baseline interaction ($p = 0.413$) provided no evidence that the relationship between baseline artwork quality and flow differed substantially between groups.

In contrast, the intrinsic goal-orientation finding was less stable. Although the unadjusted Welch comparison remained significant after Holm correction (p_Holm = 0.047), the ANCOVA result did not meet the 0.05 threshold after Holm adjustment (p_Holm = 0.0506), and the corresponding HC3-adjusted result was also nonsignificant (p_Holm = 0.062). Together with the relatively low internal consistency of this dimension, these findings indicate that the evidence for a motivation difference was weaker than the evidence for flow.

4.6. Findings in Relation to the Research Hypotheses

The between-group and within-group results were consistent with H1. Participants reported higher flow following AR-assisted observation, and the between-group difference remained statistically significant after adjustment for baseline artwork quality and robustness analysis. However, because the experimental sequence was fixed and involved additional exposure, the findings indicate an AR-associated difference rather than an effect attributable exclusively to AR.

H2 was not consistently supported. Although intrinsic goal orientation was higher in the experimental group in the unadjusted comparison, the finding was not robust across ANCOVA, multiple-comparison adjustment, HC3 estimation, and scale reliability considerations. No statistically significant group differences were found for the remaining five motivational dimensions.

Overall, the results provide clearer evidence of higher immediate reported flow associated with the AR-assisted observation activity than of broader differences in learning motivation.

5. Discussion

The findings are discussed in relation to flow experience, learning motivation, footwear design education, the contribution of the implemented AR workflow, and the methodological limitations of the study.

5.1. AR-Assisted Observation and Flow Experience

The findings indicate that AR-assisted observation was associated with higher reported flow among novice footwear design learners. The experimental group reported higher flow than the control group after adjustment for baseline artwork quality, while experimental participants also reported higher flow after AR observation than after their preceding 2D observation. The consistency of these results supports H1 within the conditions examined.

This pattern is consistent with Ibáñez et al. [41], who reported higher flow during an AR-supported learning activity than during a web-based activity. Their findings also suggested that flow depends on the characteristics and difficulty of the learning task. The present study extends this discussion to learner-created footwear designs and an AR workflow combining AI-generated 3D representations with image-triggered visualization.

One possible explanation concerns the opportunity to observe the same design from changing perspectives. Whereas the 2D condition involved a static drawing, the AR condition presented a generated 3D representation linked to the participant's original image. This may have supported sustained attention and perceived control. However, the study did not include a separate interactive 3D condition without AR. The observed difference therefore cannot distinguish the contribution of AR registration from that of 3D visualization, additional exposure, or viewpoint exploration.

The results concern an overall flow score rather than independently validated flow dimensions. They also represent immediate responses to a brief observation activity rather than sustained engagement across a design course. Furthermore, flow should not be interpreted as equivalent to spatial presence or immersion. The present evidence therefore supports a more positive immediate flow-related experience associated with the implemented AR observation activity.

5.2. Learning Motivation: Limited and Dimension-Specific Evidence

The learning motivation findings were less consistent than the flow findings. Intrinsic goal orientation was higher in the experimental group in the unadjusted comparison and remained significant after Holm correction. However, the baseline-adjusted comparison exceeded the 0.05 threshold after Holm adjustment, and the corresponding HC3 result was also nonsignificant. The remaining five motivation dimensions showed no statistically significant group differences. Consequently, H2 was not consistently supported.

This result should be interpreted in relation to differences among motivational constructs. Di Serio et al. [42] reported favorable AR effects in a visual art course using measures of attention, relevance, confidence, and satisfaction. These activity-related responses are not directly equivalent to the goal orientations, task value, control beliefs, self-efficacy, and test anxiety measured by the MSLQ. Differences between studies may therefore partly reflect differences in construct definition and measurement.

The brief intervention provides another possible explanation. A 60-s AR observation may influence the immediate experience of viewing a design without producing corresponding differences in broader beliefs about learning, competence, or course value. The activity also did not include a subsequent assessed design task through which learners could demonstrate improved competence.

The intrinsic goal-orientation result requires additional caution because internal consistency was relatively low in the experimental group ($\alpha = 0.501$). Test anxiety also showed limited reliability ($\alpha = 0.535$). These coefficients reduce confidence in precise interpretation of these dimensions. The results therefore suggest a possible difference in intrinsic goal orientation rather than robust evidence of improved learning motivation.

Finally, motivation was measured only after the final observation condition. The study cannot determine whether individual learners' motivation changed from their own baseline.

Larger longitudinal studies with pre- and post-measures would be needed to evaluate motivational change more directly.

5.3. Implications for Footwear Design Education

The findings suggest that AR-assisted visualization can complement conventional digital drawing by providing an additional observation stage in footwear design education. Within the instructional sequence examined here, 2D drawing supported concept development and visual communication, while the AR condition enabled students to view AI-generated representations derived from their own designs from different perspectives.

This application should be understood in relation to existing footwear AR research. Previous studies have applied AR to footwear customization [16], virtual try-on and foot tracking [17], and comparisons of real, VR, and AR footwear experiences [18]. Those applications primarily addressed product interaction, fitting, personalization, or user experience. The present study instead examined AR as an educational observation medium for novice designers.

Using students' own work may provide a basis for connecting observation with subsequent reflection and revision. Instructors could ask learners to identify inconsistencies between the original 2D drawing and generated 3D representation, compare proportions from different viewpoints, or propose modifications. These are potential instructional applications rather than learning outcomes demonstrated by the present study.

Practical implementation also requires technical support. Previous educational AR research has identified usability and support requirements [21]. In the present study, Tripo3D generation, Artivive setup, and researcher guidance were part of the intervention. Classroom adoption should therefore consider preparation time, model quality, operating instructions, and access to technical assistance.

The present results support the experiential value of AR-assisted observation but do not establish improvements in footwear design quality, spatial understanding, or learning achievement. These outcomes should be directly assessed in future instructional studies.

5.4. Research Contributions

This study contributes context-specific evidence concerning the integration of AR into footwear design education. Its originality does not lie in introducing AR to footwear because previous research has already demonstrated AR applications in customization, virtual fitting, and footwear-related user experience [16–18]. Rather, the contribution lies in evaluating an image-triggered AR observation workflow within an instructional context involving novice designers and their own design work.

A second contribution is the distinction between immediate flow experience and multidimensional learning motivation. The findings show that higher reported flow should not automatically be interpreted as broader motivational improvement. Flow demonstrated a consistent pattern across between- and within-group comparisons, whereas motivation results were limited and less stable.

A third contribution is methodological. Baseline artwork quality was evaluated by three lecturers and showed satisfactory inter-rater reliability, supporting its use as a covariate. Adjusting for this measure reduced the possibility that the observed flow difference was explained simply by differences in the quality of the designs being viewed. However, this adjustment does not eliminate other differences between nonrandomized cohorts or establish a causal AR effect.

The study therefore contributes an empirical evaluation of an existing AR-based design-observation workflow rather than a new AR technology.

5.5. Limitations and Future Research

Several limitations constrain interpretation. First, participants were drawn from separate existing course cohorts rather than individually randomized to conditions. Although baseline artwork quality was included as a covariate, other differences in prior experience, classroom context, or initial motivation may have contributed to the observed outcomes. The absence of a baseline artwork difference does not establish complete group equivalence.

Second, the experimental group always completed 2D observation before AR observation and therefore received additional exposure to their designs. The approximately five-minute transition also included application setup and researcher guidance rather than a validated washout period. Order, repeated exposure, additional researcher contact, and novelty remain alternative explanations. Future studies should include matched exposure durations, counterbalanced sequences, and an interactive 3D condition without AR to separate AR-specific contributions from those of three-dimensional visualization and interaction.

Third, measurement limitations warrant attention. The study-specific flow questionnaire requires further psychometric validation, while some MSLQ dimensions showed limited internal consistency. In addition, a standardized measure of presence, such as the Igroup Presence Questionnaire (IPQ) [38], was not administered. Flow should therefore not be interpreted as evidence of spatial presence or immersion. Future research could combine flow, motivation, and validated presence measures to distinguish these experiential constructs.

Fourth, the AR representations were generated automatically from single 2D images using Tripo3D. Their geometry and texture therefore represent AI-generated interpretations rather than precise CAD reconstructions of the students' intended designs. Future systems could examine higher-fidelity models, direct comparison with manually modeled 3D representations, and the effect of model accuracy on learner judgment.

Fifth, the study assessed immediate self-reported responses rather than learning performance. It did not measure subsequent design revision, design quality, spatial understanding, footwear fit, or functional performance. Future research could integrate foot morphology, gait-related visualization, or footwear deformation where these functions are relevant, while also evaluating whether increased engagement leads to improved design decisions or completed work.

Finally, the primary analysis used a modest sample from one course context. Replication across multiple classes and institutions, together with longer exposure and follow-up assessments, would help determine whether the observed flow difference represents a durable educational benefit rather than an initial response to the technology.

6. Conclusions

This study examined flow experience and learning motivation among novice footwear design learners following observation of their own designs through conventional 2D drawings and an AR-assisted visualization workflow. In the AR condition, students' 2D footwear drawings were converted into AI-generated 3D models using Tripo3D and subsequently deployed through Artivive as image-triggered AR content.

The results showed that the experimental group reported higher flow after AR observation than the 2D control group, and this difference remained significant after adjustment for baseline artwork quality. Experimental participants also reported higher flow after AR observation than after their preceding 2D observation. These findings indicate that the implemented AR-assisted activity was associated with a more engaging immediate observation experience.

Evidence for learning motivation was less conclusive. Although intrinsic goal orientation was higher in the experimental group in the unadjusted comparison, the result was not consistently supported after covariate adjustment, multiple-comparison correction, robust estimation, and consideration of scale reliability. No significant group differences were identified for the remaining motivation dimensions. The findings therefore do not establish a broad improvement in learning motivation.

The study contributes evidence that image-triggered AR can complement conventional 2D representation as an observation medium in footwear design education. However, the findings concern immediate self-reported experience and should not be interpreted as evidence of improved design quality, learning achievement, spatial ability, or footwear functionality. Because the groups were nonrandomized, the observation sequence was fixed, and the AR condition involved additional exposure and researcher support, the observed differences cannot be attributed exclusively to AR technology.

Future research should employ matched and counterbalanced comparison conditions, include interactive 3D visualization without AR, and incorporate validated measures of presence alongside flow and motivation. Longer-term studies should also examine whether AR-supported observation contributes to design revision, design judgment, learning performance, and higher-fidelity footwear evaluation.

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Institutional Review Board Statement: This study was conducted in accordance with the ethical principles governing human subjects research. Article 5 of Taiwan's Human Subjects Research Act requires prior ethical review of research involving human participants unless the study falls within an exemption category designated by the competent authority. According to Item 4 of Department of Health Announcement No. 1010265075, dated 5 July 2012, studies evaluating teaching methods or their effectiveness in ordinary educational settings may qualify for exemption from ethical review. In this study, data were collected through questionnaires designed to assess students' flow experience and learning motivation during routine course activities. The study was not formally submitted for ethical review before implementation, and no formal exemption determination was obtained. However, the nature of the study is consistent with the educational research category described in the aforementioned regulation.

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

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