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Effectiveness of Team Virtuality in Design Studio Education

-- A Case Study of Smart Glove Design Project

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Abstract: Virtual studio education has become an important topic in design education, as Design Studio Education (DSE) increasingly moves beyond physical constraints and incorporates virtual design tools and workspaces. Although prior research has examined the impact of virtuality on DSE, most studies adopt a simple "virtual vs. non-virtual" comparison, leaving the effects of varying degrees of virtuality largely unexplored. This study investigates how different levels of team virtuality affect students' collaborative experiences and innovation performance in DSE. Using a smart glove design project, studio groups with low, medium, and high virtuality were compared across five indicators: innovation climate, silence behavior, fluency and rarity of ideas, and creativity, using one-way analysis of variance (ANOVA). Results show that higher virtual communication negatively affects trust-building and information-sharing among students. In contrast, the use of virtual tools positively enhances students' creativity. An integrated online-offline DSE model demonstrates the most balanced performance, supporting both collaboration and innovation. These findings highlight the importance of fostering positive team interactions in virtual DSE, enabling students to leverage virtual technologies to improve professional skills in a supportive innovation environment.

Keywords: Design Studio; Design Education; Team Virtuality.

1. Introduction

Design Studio Education (DSE) is a prominent method for teaching design professions. Nowadays, virtual work has become the new normal [1], which has prompted DSE to shift from physical spaces to online or online-offline integrated models [2]. Team virtuality, conceptualized as a continuous variable measuring the degree of the virtuality of an organization, facilitates a more precise quantification of the virtual characteristics of different design studios and a more precise study of the impact caused by virtual studios on the students' collaborative process [3]. Unlike the conventional theoretical lecture model, DSE involves numerous social and practical experiential activities [4]. In DSE, students communicate and create with teachers and peers and learn by doing. Students transform from bystanders to practitioners of knowledge, thus enhancing their ability to collaborate and innovate. Compared with the traditional DSE model, virtual DSE faces opportunities and challenges in the transformation process and impacts on students' collaboration processes, innovative achievements, and overall experience [5]. To a certain extent, the virtual DSE model enables students to show more independence and creativity [6, 7], but there are also problems such as decreased student satisfaction and weakened peer learning [8, 9].

The focal point of this inquiry lies in the examination of the impact of virtuality on DSE models. Existing studies tend to adopt a dichotomous approach, making comparisons between physical and virtual DSE models. However, there is a paucity of research that has examined diverse DSE models through the lens of a team virtuality model. The degree of virtuality of different DSE models may exert a distinct influence on members' psychological feelings, interaction states, and innovation outcomes. A systematic investigation of DSE models through the lens of virtuality can offer a more profound comprehension of the direct impact of virtualization transformation on DSE models. This, in turn, can catalyze the development of future virtual DSE models.

This study is based on a participatory wearable design project in which teachers and interdisciplinary students formed different studio groups to co-create smart gloves. Firstly, an examination of relevant literature was conducted to identify issues facing the DSE model under virtualization transformation. Then, the impact of team virtuality elements on the DSE model was explored through a smart glove design project study. The study utilizes a virtuality model to quantify the degree of virtuality of different studio models and evaluates 5 indicators of innovation climate, silent behavior, thinking fluency and rarity, and creativity in the design process of studio teams with low, medium, and high levels of virtuality. The study provides a comparative analysis of these indicators, thereby substantiating the merits of the integrated DSE model. Finally, the indicators obtained and phenomena observed in the design practice were analyzed to explore the mechanism of the influence of team virtuality on students' psychological feelings and innovative performance in the DSE context. The ultimate goal of this study is to enable future DSE to positively utilize the advantages of team virtuality, to appropriately deal with virtual communication and cooperation in design education, and to promote the ability cultivation of design talents in the new era.

2. Literature Review

2.1. Design Education in Traditional Studios

The studio model has always played a vital role in design education. Design studios can provide students with the space and materials they need, enabling members to learn through projects and thus cultivate independent and professional

creative practitioners [10]. In a design studio, students are guided by a mentor, work together, share creative ideas, test solutions, and present results, creating an interactive knowledge-sharing environment that allows students to learn through reflection in action, resulting in a special learning culture [11]. Instead of being passive recipients of knowledge, students accomplish learning of knowledge, skills, and values while interacting with their peers in the design studio. Studies have concluded that DSE can effectively hone students' knowledge-building, design creativity, teamwork, effective communication [12], and multi-dimensional thinking skills [13]. Generally, traditional design studios rely on a physical space where students and faculty can invest a significant amount of time. Students gather in the physical space of the studio to engage in a variety of creative activities, including collaborating, conceptualizing, drawing, fabricating, and realizing designs, as well as interacting in workshops, presentations, and critiques [5]. The physical space of the studio can be an open area with tables and chairs or specially constructed spatial units, which is often filled with sticky notes, sketches, physical models, etc. [4].

The traditional DSE model emphasizes co-creation, practice, experience, and interaction, effectively cultivating design students' ability to learn from each other, do hands-on practice, social interaction, and collaborative innovation. In addition, the open design atmosphere and spacious environment in the studio allow for the introduction of diverse design projects and members, narrowing the gap between disciplines and between universities and enterprises, and promoting the cultivation of design talents. For example, Kim, Ju and Lee [14] formed collaborative design studio groups with students from different cultural backgrounds and fields of specialization and concluded that this form can give students non-traditional perspectives and promote divergent thinking, thus enhancing the effectiveness of design education.

However, traditional physical design studios are facing challenges. Firstly, from an economic perspective, the open space and specialized faculty required for physical design studios are undoubtedly resource-intensive and expensive, and the growth in the number of students due to the expansion of higher education has further exacerbated this economic burden [15]. Secondly, from the perspective of network technology, online design studios based on virtual platforms have become an alternative, prompting the creation of more virtualized online design studios. Thirdly, from the perspective of talent cultivation, virtual work has become the new normal in current business organizations [1]. With the further development of information and communication technologies, the communication media and collaboration methods used within enterprise teams are becoming increasingly rich, making the connotation of the virtual team constantly updated. At present, the virtual team has developed into a collaborative workgroup supported by digital and intellectual technologies, across time and space, and across organizations, dedicated to accomplishing the target tasks [16]. This shift in the form of business organizations has also prompted the transformation of DSE. Although studies have shown that face-to-face learning is still the primary choice for teachers and students in design education [17], purely online or online-offline combined studio models have already been adopted in an increasing number of design teaching activities[18, 19].

2.2. Design Education in Virtual Studios

Team virtuality is a variable used to measure the degree of virtualization of different teams. Research on virtual teams emerged in the 1990s [20]. The more a team is characterized as a virtual team, the higher its virtuality. Early studies of virtual teams generally categorized teams as “virtual” or “non-virtual” based on whether they relied on electronic communication [21]. This classification does not clearly reflect the diverse forms of virtual teams in reality. Currently, scholars generally consider team virtuality as a continuous multi-dimensional concept [22], to better explain different virtual team forms.

The new form of DSE under the influence of digitalization presents a higher degree of virtuality. This new organizational form can be called a virtual design studio. There exist different perspectives in academia on the dimension of team virtuality. Huang and Liu [22] integrated previous viewpoints and proposed a three-dimensional team virtuality model from the perspectives of people, technology, and organization, including "team members' dependence on virtual tools", "the richness of communicated information", and "the diversity of team members". The virtualization of design studios is mainly reflected in 2 aspects: “virtualized design tools” and “virtualized workspaces” [7, 23].

At the tool-application level, the virtual design studio has shifted from traditional physical tools to intelligent collaborative tools. This shift begins with the paperless and digitalization of studio design tools. Students use tools such as virtual drawing boards and modeling software to replace traditional pen and paper, and learn how to think and design using digital media in the process of completing design tasks [24]. On this basis, the tools of virtual studios are further evolving towards sharing and intelligence. In terms of virtual tool sharing, design tool software with real-time sharing and collaboration functions, such as Figma, enables design tasks that originally required to be completed by members in a scattered manner to be carried out simultaneously on a virtual whiteboard, greatly improving the efficiency and information richness of virtual collaboration. Shared virtual design tools make the working process and results in the working room to be completely retained, which is convenient for group members to communicate and review. In terms of virtual tool intelligence, with the rapid rise of artificial intelligence, open-access AIGC tools have been able to do the generation of text, images, code, etc.[25, 26]. Although AI tools have raised concerns in the educational community about the decline of students' cognitive, logical, and academic abilities [27], how to make AI technology effectively serve virtual DSE remains a very important topic.

At the spatial-environment level, the virtual design studio has shifted from a physical space to an online virtual environment. Through the Internet and online cooperation, geographically dispersed students can still jointly complete design work and form a virtual studio across time and space. By breaking through the limitations of physical space, virtual design studios are not restricted to campus spaces and fixed time schedules, enabling collaboration between students from different disciplines and cultural environments [28]. Virtual studios use online collaboration technologies, including applications such as email, video conferencing, and meta-universe work communities, to achieve dialogue and collaboration among members in an online learning environment[29]. While the virtual work environment expands the temporal and spatial scope of the studio, it also,

to a certain extent, leads to the distortion of information such as tone, demeanor, movement, and contact during communication among members. This may lead to mutual alienation among members, limiting the ability of design studios to cultivate students' team-collaboration and innovation-climate-building skills. However, by combining technologies such as facial capture and VR, the virtual workspaces may provide a more immersive, gamified, and rich experience, enabling teachers and students around the world to carry out design studio education in a more complete virtual space across time and space limitations.

Compared with traditional studios, virtual design studios show certain advantages in terms of design efficiency and outcomes. In a virtual learning environment, students demonstrate greater independence and more active self-learning behaviors [7]. Rong, Lian and Tang [6] demonstrated that integrating virtual reality (VR) interaction and artificial intelligence (AI) into art education promotes deep learning for students, enhancing their concentration and creativity. Liu, Wu, Lyu and Sun [30] developed a collaborative design platform and used complex networks to analyze multiple key elements of collaboration, concluding that an open collaborative innovation platform can help improve team design efficiency.

However, virtual studios have disadvantages in terms of social interaction, background learning, and peer learning [7]. Research shows that students' overall satisfaction with the online studio experience is low[8]. Students usually have difficulty trusting fellow strangers in virtual studios, especially when it comes to design communication [31]. Due to the lack of real-world immediate feedback, students' motivation and attention levels are negatively affected [17]. Zhu, Vennemeyer, Xu and Wu [32] found that the virtual office spaces are not conducive to informal communication among members, which may affect the establishment of trusting relationships among members. To address such issues, studies have suggested that a blended learning model that combines the advantages of face-to-face and online education may be more suitable for the current DSE system [17, 18, 33, 34].

The advantages and disadvantages presented by the virtual DSE model over the traditional model can be explained from the perspective of the virtuality variable. Team virtuality affects the process of team functioning and, ultimately, the outcomes of teamwork. The mechanisms by which virtuality affects team functioning are complex and have led studies to present contrasting findings. Some studies suggest that higher virtuality has a positive impact on team functioning. Virtual teams can better integrate resources and reduce communication costs, thus improving overall team performance [35]. Conversely, some studies have pointed out that high virtuality hinders emotional connection and trust building among team members, instead inhibiting team performance [36]. In this regard, Liang, Deng, Yan, Ma and Li [37] hypothesized a theoretical model of the influence mechanism of the impact of team virtuality on team performance, arguing that virtuality affects team performance by promoting the “information transfer ability” within a team and inhibiting the “willingness to share information” among its members, and that virtuality has an impact on team performance. The extent to which virtuality facilitates and inhibits information exchange in teams is influenced by the stage of team development. In addition, Overby [38] states that a "virtual" process is one that eliminates physical interactions between people and objects. Teams are more virtual when the level of such physical interactions in the team is low. Makarius and Larson [39] describe virtuality in terms of individual perceptions, suggesting that virtuality reflects the extent to which individuals use modern technology to interact with other members, share ideas and information, and perform work. This reflects the fact that team virtuality is not only an objective attribute of a virtual team but also related to the subjective feelings and interactive behaviors of people. Even if there is an objectively large physical distance and few physical interactions among members, individuals may still perceive a closer psychological distance through richer and more fluid forms of virtual interaction, such as online meeting rooms and online edited documents shared in real time.

3. Research Model and Hypotheses

Based on the theoretical analysis framework of the "double-edged sword" effect of team virtuality [37], and combined with the initial formation of studio groups in the DSE model and the team characteristics aiming to complete short-term tasks, an impact model of virtuality on DSE was developed, as shown in Fig 1.

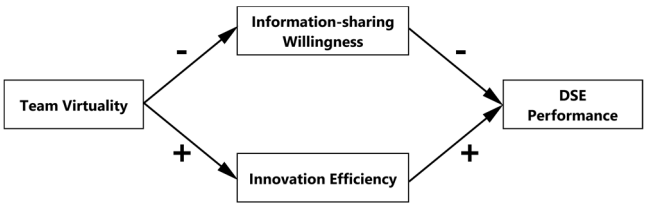


Fig 1. Model of the Impact of Virtuality on DSE

Regarding the impact of virtuality on DSE, this study puts forward hypotheses in the following 2 aspects:

1) In terms of people's subjective feelings, there is a negative correlation between virtuality and the willingness of studio members to share information;
2) At the design implementation level, there is a positive correlation between virtuality and work innovation efficiency among studio members.

For the above hypotheses, this study will explore the impact of team virtuality on design studio education through a case comparison experiment with the help of practical observation, expert ratings, and scale assessment.

In terms of subjective feelings, the study mainly investigates 3 indicators, namely, “team-perceived virtuality”, “team innovation climate”, and “members’ silence behavior”. The team-perceived virtuality scale[22] is used to measure members' perceived virtuality and explore the effects of different virtual means on members' perceived virtuality. The team innovation climate scale[40] is used to measure the degree of innovation support that members feel from others during the practice process. The silence behavior scale[41] is used to explore the extent to which members choose not to express their better ideas during practice. These 3 indicators can reflect the direct feelings of design studio members about the cooperation process, as well as the actual impact of these feelings on their ideological expression and team atmosphere.

In terms of design implementation, the study examined 3 indicators: "fluency of ideas", "rarity of ideas", and "creativity". Fluency and rarity of ideas are measured by coding and comparing the details of different ideas, which are obtained based on the quantity and rarity of each team's

solution ideas. Creativity is scored by expert judges from the dimensions of the functional combination, appearance aesthetics, safety, and economy of the final solution. The above indicators can reflect the thinking efficiency, innovation ability, and outcomes of studio members.

Through the combination of subjective and objective indicators, it is possible to comprehensively consider the impact of virtuality on the feelings, behaviors, and outcomes of members in DSE, and to more fully explore the opportunities and challenges of design studio virtualization on design education and innovation.

4. Methodology

4.1. Research Objectives

As a cutting-edge form of intelligent products, the design of smart wearable devices integrates multi-disciplinary knowledge, including materials science, Internet of Things, design, etc. [42-44]. Existing products such as Apple Watch and Samsung Galaxy Gear, which are bracelet-type devices, have achieved certain market success. In addition, clothing-type products like Levi's X Jacquard and Nike Adapt BB, and head-worn devices such as Google Project Glass and Apple Vision Pro have all expanded the connotation and boundaries of smart wearable devices. With the further development of sensing and interaction technologies, wearable design is expected to become a direction that changes the future lifestyle of humanity. Relying on interdisciplinary design teams, it is expected to promote the birth and progress of new wearable products.

As a special form of team, the cooperation process and outcomes of design studio members are influenced to a certain extent by the virtuality of the studio team itself. In this study, we conduct an intelligent glove design experiment by forming 3 design studios with different degrees of virtuality. By comparing 3 types of indicators, namely member behavior, innovation climate, and innovation outcomes, during the cooperation process of the design studio groups with low, medium, and high degrees of virtuality in pure physical collaboration, online-offline combined collaboration, and pure virtual collaboration, this study aims to research the impact of virtuality on studio teams and explore better strategies for virtual DSE.

4.2. Participants and Instrument

In this experiment, 12 students were randomly assigned to 3 design studio groups. 9 of them were postgraduate students majoring in design, and 3 were postgraduate students majoring in Internet of Things Engineering. Each group consisted of 3 design-major students and 1 IoT-Engineering-major student, and they carried out a two-week design studio practice under the guidance of one faculty member in each group.

The experiment was divided into a total of 3 design studio groups. Each group conducted design research under the selected spatial environment and cooperation tool conditions. The members of the first group communicated face-to-face in an offline physical environment and mainly used physical tools such as paper and pens for cooperation, which is abbreviated as the F-P group. The members of the second group cooperated using an online sharing platform in an offline physical environment, abbreviated as the F-S group. The members of the third group worked entirely in an online virtual environment and cooperated using an online sharing platform in an online meeting room, abbreviated as the O-S group.

As shown in Fig 2, according to the dimensional model of virtuality, the higher the diversity of members, the higher the degree of dependence on virtual tools, and the lower the richness of communication information, the higher the degree of virtuality of the team. Given that the disciplinary background compositions of the 3 groups of members are similar, the differences in the forms of communication and cooperation among members will affect the degree of virtuality of the team. Compared with face-to-face communication, the communication form of online video conferencing will lead to the loss of rich information contained in body movements, expressions, and eye and physical contact. Compared with a physical workbench, a virtual whiteboard workbench will reduce eye-to-eye communication and physical contact among members, thus reducing the richness of information in actual collaboration. Therefore, based on the virtuality theory, the F-P group, F-S group, and O-S group belong to the low-virtuality, medium-virtuality, and high-virtuality levels respectively.

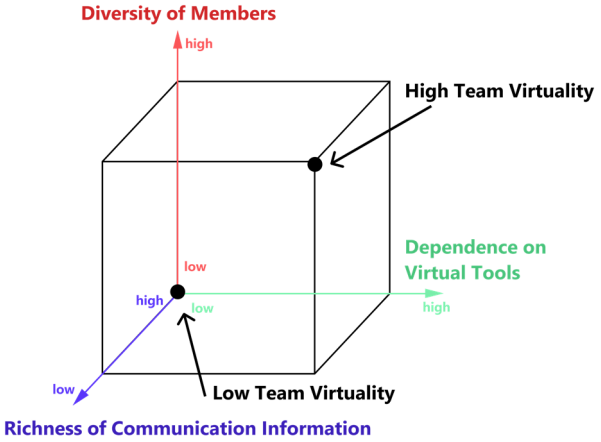


Fig 2. Dimensional Model of Team Virtuality [22]

The specific communication and cooperation media used in the experiment include:

1) Physical communication methods: Offline face-to-face communication;
2) Asynchronous virtual communication methods: Text or voice messages, emails, etc.;
3) Real-time virtual communication methods: Virtual meeting rooms;
4) Physical design tools: Paper, pens, whiteboards, sticky notes, etc.;
5) Non-shared virtual tools: Information search channels such as search engines and social media, and AI-generation tools like ChatGPT and Midjourney;
6) Shared virtual tools: Shared documents, shared whiteboards like Figma, etc.

The tool usage of each studio group is shown in Table 1.

Members of each group are allowed to use forms such as text messages and emails for simple communication before meetings to arrange working hours. During real-time communication, members of the F-P group and the F-S group will communicate face-to-face in an offline open space, while the O-S group will communicate via voice-based online meetings. At the same time, during the practice process, members of the F-P group record the design process with pens, sticky notes, white paper, and whiteboards. Members of the

F-S group and the O-S group co-create through a virtual shared whiteboard on the screen. It should be noted that each group is not restricted from using non-shared virtual tools such as search engines. Since members cannot directly communicate in real-time through non-shared virtual tools, the use of non-shared virtual tools is not uncommon in current design studios.

Table 1. Allocation of Tool Usage in Each Design Studio Group

	F-P	F-S	O-S
Medium 1: Physical Communication	√	√	×
Medium 2: Asynchronous Virtual Communication	√	√	√
Medium 3: Real-Time Virtual Communication	×	×	√
Medium 4: Physical Design Tools	√	×	×
Medium 5: Non-Shared Virtual Tools	√	√	√
Medium 6: Shared Virtual Tools	×	√	√

4.3. Design Tasks

All 3 teams were required to design a wearable smart glove product with intelligent functions and experiences that adapt to the form of hand interaction. Before the design practice started, the design task was presented on a public whiteboard. The research mainly focused on the information exchange, idea generation, and innovation capabilities of studio members during collaborative work. In this practice, the glove, as a design carrier, has 2 advantages. Firstly, gloves are common daily necessities, and participants do not need knowledge beyond common sense to understand the task requirements. This ensures that every participant has the basic ability and motivation for information communication and sharing. Secondly, the smart glove product has not formed a single and rigid product impression, thus avoiding restricting the members' thinking and making the creative results rely more on innovative communication within the team rather than other background knowledge. By comparing and paying attention to the communication and collaboration of the 3 groups of members in the design studio, we can explore the impact of virtuality on the feelings, behaviors, and ability development of members in DSE.

4.4. Procedure

The experimental process is shown in Fig 3 and Fig 4. Each design studio group received a design brief marked on the whiteboard from the experimenter. Team members were required to communicate with each other throughout the process, and the cooperation process among members was recorded using a video camera. The 3 groups carried out their cooperation according to a unified work process and time regulations. The experimental process is divided into 4 stages: problem exploration, opportunity definition, prototype development, and result delivery:

In stage 1, each group was required to generate as many ideas as possible through communication, record them, and add sketches and annotations if necessary.

In stage 2, members needed to select one of the ideas and deepen it, confirming information such as the functions, materials, and target users of the design plan.

In stage 3, each design studio team, based on the refined plan, completed the appearance presentation of the smart glove plan and listed its advantages and design details as comprehensively as possible.

In stage 4, the plan results of each group were evaluated and scored by 5 independent judges who were unaware of the experimental objectives and conditions. In addition, after completing the task, members of each studio group were required to anonymously answer a short scale questionnaire to examine their perception and feelings about this collaborative design studio cooperation.

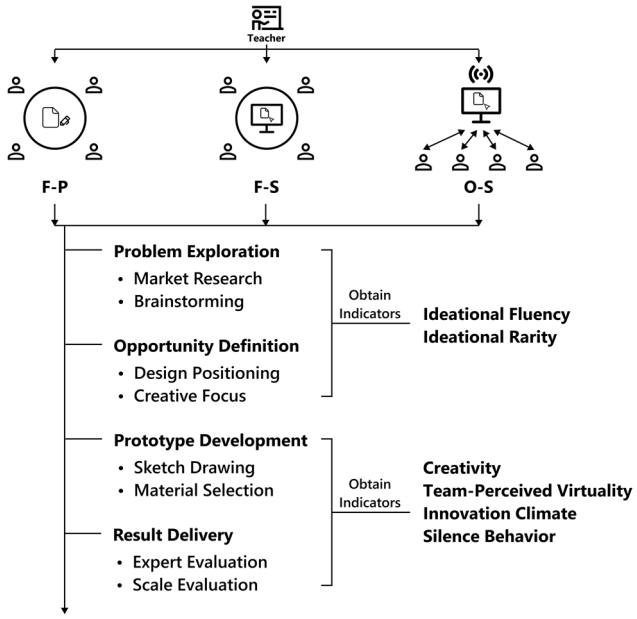


Fig 3. Framework of Organizational Structure and Practice Process

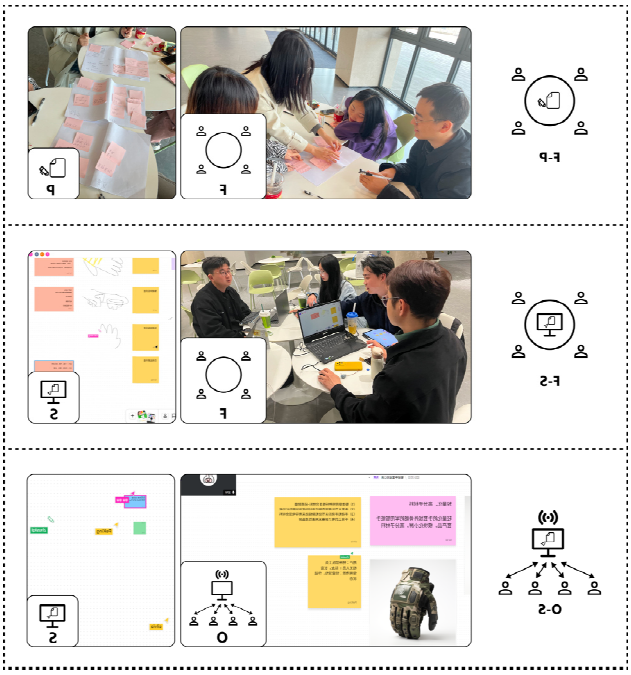


Fig 4. Cooperative Scenarios of Each Studio Group

4.5. Evaluation Criteria

As shown in Table 2, in the first and second stages of the practice, the evaluation is based on the creative ideas generated by each studio group, including fluency and rarity of ideas of each group. Fluency of ideas is measured based on

the objective number of ideas generated by each design studio group. Rarity of ideas is reflected by the ideas that are relatively rare among all the ideas generated in a specific environment. In this practice, the ideas generated by each team will be classified uniformly and compared horizontally. The creative ideas with a lower frequency of occurrence will obtain a relatively higher score for the rarity of ideas.

Table 2. Sub-table of Evaluation Criteria

Stage	Indicator	Evaluation Method	Evaluation Dimension	Virtuality Issue
Stage 1 & 2	Fluency of Ideas	Objective Indicator – Idea Coding and Counting	Total Number of Ideas	Impact on Work Performance
	Rarity of Ideas	Objective Indicator – Idea Frequency	Proportion of Rare Ideas	Impact on Work Performance
Stage 3 & 4	Creativity	Expert Rating – Innovation Outcomes Evaluation	Functional Combination Appearance Aesthetics Safety Economy	Impact on Work Performance
	Team-perceived Virtuality	Subjective Self-Assessment – Perceived Virtuality Scale	Diversity of Members Richness of Information Dependency on virtual tools	Impact on Subjective Feelings
	Innovation Climate	Subjective Self-Assessment – Innovation Climate Scale	Peer Support Leadership Support Organizational Support	Impact on Subjective Feelings
	Silence Bahavior	Subjective Self-Assessment – Silence Behavior Scale	Silence Behavior	Impact on Feelings & Behaviors

In the third and fourth stages of the practice, the creativity of each studio group is evaluated. The reviewers will receive the smart glove design plans of the 3 teams in random order and score the functional combination, appearance aesthetics, safety, and economy of the design output of each team based on a 10-point Likert scale. The final creativity score is the sum of the average scores on the Likert scale.

In addition, after the completion of the design practice, each member is required to fill out a questionnaire anonymously. The questionnaire consists of 3 parts: the Team Virtuality Scale, the Team Innovation Climate Scale, and the Silence Behavior Scale. The semantics of each scale have been slightly adjusted to adapt to the actual structure of the team. The Team Virtuality Scale is used to measure the team-perceived virtuality of each member, to test the members' actual perception of the degree of virtuality of the design studio team. The Team Innovation Climate Scale is used to test the members' perception of the innovation climate of the studio team they are in, to understand whether the members feel supported during the cooperation process. Silence behavior refers to the behavior in which members choose to keep their opinions to themselves without expressing them when they find problems in the team or have optimization ideas. Through the Silence Behavior Scale, we can understand the degree of occurrence of members' silence behavior during the cooperation process in each studio group.

Based on the hypothesis of the impact of team virtuality on DSE, the following hypotheses can be further proposed for this experiment:

1) In terms of the establishment of trust relationships and the willingness to share information, the face-to-face communication (F) group in the offline environment will perform better than the virtual meeting communication (O) group in the online environment. That is, the F group will have a better innovation climate and fewer silence behaviors;
2) In terms of cooperation efficiency and creative achievements, the group that uses the online sharing platform for cooperation (S) will perform better than the group that does not use it (P). That is, the S group will obtain higher scores in fluency of ideas, rarity of ideas, and creativity;
3) The face-to-face communication mode in the offline environment with the use of an online sharing platform is a relatively better strategy for the design studio model under the influence of virtuality. That is, the F-S group will perform better than the F-P group and the O-S group in all evaluations.

5. Results

Following two weeks of design studio practice, each team produced a distinct smart glove concept:

The F-P group developed a tactile-feedback glove leveraging hand-motion capture to simulate the sensation of interacting with physical objects.

The F-S group designed a daily-commute glove incorporating NFC technology for identity verification and electronic payments.

The O-S group proposed an outdoor adventure glove featuring embedded display-based functionalities for navigation, positioning, and remote control.

5.1. Team-perceived Virtuality

Table 3 presents the results of a one-way ANOVA comparing the three studio groups on three team virtuality indicators: member diversity, communication information richness, and virtual tool dependence. Higher scores indicate a lower perceived level of virtuality.

Results revealed no significant differences in member diversity across groups. However, significant differences were observed in communication information richness and virtual tool dependence. Post-hoc Tukey tests indicated that the O-S group reported significantly lower communication richness compared to the F-P group (mean difference = −5.00, $p = 0.048$) and the F-S group (mean difference = −5.75, $p = 0.025$). Similarly, the O-S group showed significantly higher virtual tool dependence relative to the F-P group (mean difference = −8.75, $p < 0.01$) and the F-S group (mean difference = −7.00, $p = 0.012$). No significant differences were found between the F-P and F-S groups for either communication richness (mean difference = −0.75, $p = 0.91$) or virtual tool dependence (mean difference = 1.75, $p = 0.64$).

5.2. Innovation Climate

Table 4 summarizes the results of a one-way ANOVA comparing the three studio groups on three dimensions of team innovation climate: peer support, leadership support, and organizational support. Higher scores indicate a more favorable perception of the team's innovation climate.

Table 3. Perceived Virtuality of DSE Groups

Indicator	F-P		F-S		O-S		F	*p*
	Mean	SD	Mean	SD	Mean	SD		
Member Diversity	15.5	0.58	16.75	2.36	16.75	1.26	0.83	0.47
Communication Information Richness	15.5	2.38	16.25	2.22	10.5	2.89	6.20	0.02*
Virtual Tool Dependency	24	2.71	22.25	2.36	15.25	2.87	12.15	<0.01*
Total Mean Score	56.25		55.25		42.5			
*Significant at $p<0.05$								

The analysis revealed no significant differences in leadership support or organizational support across groups. However, a significant difference was found in peer support. Post-hoc Tukey tests showed that the O-S group reported significantly lower peer support than the F-P group (mean difference = −2.75, p = 0.038). No significant differences were observed between the F-P and F-S groups (mean difference = 0.25, p = 0.96) or between the F-S and O-S groups (mean difference = 2.50, p = 0.058).

Table 4. Innovation Climate of DSE Groups

Indicator	F-P		F-S		O-S		F	p
	Mean	SD	Mean	SD	Mean	SD		
Peer Support	18	0.82	17.75	1.71	15.25	1.26	5.37	0.03*
Leadership Support	16.75	3.40	17	2.45	16.5	1.91	0.04	0.97
Organizational Support	17	1.83	16.75	2.06	16.75	2.06	0.02	0.98
Total Mean Score	51.75		51.5		48.5			
*Significant at $p<0.05$								

5.3. Silence Behavior

Table 5 presents the results of a one-way ANOVA comparing silence behavior across the three studio groups. Higher scores indicate a greater tendency for team members to withhold their ideas. The analysis revealed significant differences among the groups. Post-hoc Tukey tests showed that the O-S group exhibited significantly higher silence behavior than both the F-P group (mean difference = 4.75, p = 0.023) and the F-S group (mean difference = 5.25, p = 0.014). No significant difference was observed between the F-P and F-S groups (mean difference = 0.50, p = 0.936).

Table 5. Silence Behaviors of DSE Groups

Indicator	F-P		F-S		O-S		F	p
	Mean	SD	Mean	SD	Mean	SD		
Silence Behavior	9.25	2.22	8.75	1.71	14	2.16	8.06	0.01*
*Significant at $p<0.05$								

5.4. Fluency and Rarity of Ideas

Table 6 summarizes the coding and classification of solution ideas generated by each studio group, based on both appearance structure and functional features. Ideas that appeared only once across all groups were classified as rare ideas. The results indicate that the F-P group generated the highest total number of ideas, exceeding those of the F-S and O-S groups. The proportion of rare ideas in the F-P group was also slightly higher than that of the F-S and O-S groups, although the differences in rarity ratios were minimal.

Table 6. Statistics on the Ideas of DSE Groups

Group	Rare Ideas	Total Number of Ideas	Rarity Ratio
F-P	9	32	28.1%
F-S	7	25	28.0%
O-S	6	22	27.3%

5.5. Creativity Scores

Table 7 presents the results of a one-way ANOVA conducted on expert evaluations of the smart glove designs across the three studio groups, assessing functional combination, appearance aesthetics, safety, and economy. The analysis revealed significant differences in safety scores. Post-hoc Tukey tests indicated that the F-P group scored significantly lower in safety than the F-S group (mean difference = -1.60, p = 0.042) and the O-S group (mean difference = -1.80, p = 0.022). No significant difference was observed between the F-S and O-S groups (mean difference = -0.20, p = 0.936). The total mean creativity scores were 24.8, 27.2, and 28.0 for the F-P, F-S, and O-S groups, respectively.

6. Discussion

This study focused on the impact of team virtuality on member behaviors, perceptions, and creativity in DSE. By systematically controlling the communication and collaboration media across different smart glove design

groups, we evaluated both the collaborative processes and outcomes, alongside members' subjective perceptions. The findings suggest that integrating a real-world communication environment with a real-time shared virtual work platform represents an effective model for DSE. The results further indicate that digital media technologies can enhance and complement traditional studios, while virtual studios introduce fundamental changes to design studio pedagogy.

Table 7. Expert Evaluation of DSE Groups

Indicator	F-P		F-S		O-S		F	*p*
	Mean	SD	Mean	SD	Mean	SD		
Functional Combination	6.2	0.84	5.8	1.64	7.0	1.22	1.14	0.35
Appearance Aesthetics	7.4	1.14	7.8	0.84	7.4	1.14	0.07	0.93
Safety	6.0	0.71	7.6	0.89	7.8	1.10	5.84	0.02*
Economy	5.2	0.84	6.0	1.22	5.8	1.30	0.67	0.53
Total Mean Score	24..8		27.2		28			
*Significant at $p<0.05$								

6.1. Discussion on the Effectiveness of Virtuality on Students' Feelings in DSE

This study sought to investigate the impact of virtuality on the behaviors and sentiments of students in design studios. To this end, an evaluation was conducted to assess the psychological perceptions of the participants. The results indicated that members of the O-S group exhibited a stronger perception of virtuality. While members of the F-S group demonstrated a heightened sense of virtuality compared to those in the F-P group, the difference was not statistically significant. Due to the random and average grouping of personnel, there was no significant difference in the perception of team member diversity among the members of each group. The differences in virtuality perception among different types of groups were mainly reflected in the dimensions of communication information richness and virtual tool dependence. This result demonstrates that the virtual or real nature of the environment where team members communicate exerts a stronger impact on members' perception of virtuality than the virtual or real nature of the cooperation tools used by members during work. The findings of this study further suggest that the physical space provides more flexibility for designers' daily social interactions and introduces heterogeneity and informality into the design cooperation process [4]. In this study, although members of the F-S group did not work together on the same physical whiteboard during the cooperation process, but operated while watching the screens of their respective electronic devices, they could still feel a real-world connection. This phenomenon occurred because the designers were in the same physical space, rather than communicating with each other through speakers and microphones.

In the evaluation of the perception of the team innovation climate perception, the O-S group members' scores in the peer-support dimension were significantly lower than those of the F-P and the F-S groups. However, no significant differences were observed among the groups in the leadership-support and organizational-support dimensions. This may be due to the unified guidance provided, leading to a uniform perception of innovation support from teachers and the team among members of each group. The absence of opportunities for students in an online design studio to experience the studio with their peers and share their mental burdens with others may lead to feelings of loneliness and a loss of motivation [2]. When members of the O-S group felt a lack of support, they were more inclined to attribute this sense of deficiency to other members of the group. The investigation of members' silence behavior revealed that the frequency of members in the O-S group choosing to engage in silence behavior was significantly higher than that of the F-P group and the F-S group. This finding lends further support to the "double-edged sword" effect hypothesis of team virtuality [37]. In the context of short-term design studio teams, virtuality exhibits a negative correlation with the establishment of trust relationships and the propensity to share information among team members. This finding serves to substantiate the initial inquiry posed in this paper: specifically, that in terms of trust relationship development and information sharing, face-to-face communication groups in offline environments demonstrate superior performance in comparison to virtual meeting communication groups in online environments. The impact of a more authentic communication environment and state on the psychological well-being of design studio members is found to be significant. The virtual work environment has been shown to impede informal communication and collaboration among members, potentially leading to adverse emotional responses and passive behaviors [32].

6.2. Discussion on the Effectiveness of Virtuality on Innovation Performance in DSE

In the evaluation of fluency and rarity of ideas, the F-P group generated a comparatively higher number of ideas, with a concomitant increase in the proportion of rare ideas among their ideas. However, the gap in the rarity of ideas among different types of groups was not found to be statistically significant. A more comfortable innovation climate and a stronger willingness to share do seem to increase the number of ideas, but they do not have a significant impact on the rarity of ideas. In the context of a design studio, students cultivate collective understanding and knowledge through dialogue and negotiation [31]. Research indicates that this cooperative culture persists in the virtual environment, and design studio groups with varying degrees of virtuality exhibit comparable levels of thinking.

Following the evaluation of the smart glove design plans by the judges, the O-S group was found to have obtained the highest creativity score, while the F-P group received the lowest score. Notably, the F-P group's score in the safety dimension of the plan was significantly lower compared to that of the other groups, resulting in a comparatively lower creativity score for the F-P group.

This outcome aligns with the hypothesis posited in the second question, which stated, “in terms of cooperation efficiency and creative achievements, the group that uses the online sharing platform for cooperation performs better than the group that does not”. The utilization of an online sharing platform for cooperation enables members to comprehensively review the progress of the work, observe the work parts that each member is handling, and complete the work synchronously. In contrast, the utilization of physical whiteboards or documents necessitates the allocation of distinct physical spaces for each member, thereby hindering the uniformity of their view and operational capabilities. The employment of virtual shared whiteboards or documents enables members to maintain a uniform perspective and operational capacity, irrespective of their physical location. Conversely, the use of physical whiteboards, paper, pens, and sticky notes imposes limitations on the members' view, hindering their ability to zoom in or out to view the work content. Furthermore, the social distance between members impedes their collaborative operations on local components. This disparity might have led to blind spots in the F-P group's cooperation process, contributing to a lower creativity score. Additionally, the F-S group did not achieve the highest creativity score, which does not align with the expectations outlined in the third question. While the data demonstrate that the organizational structure of the F-S group, to a certain extent, circumvents the deficiencies that may be engendered by the virtuality of the F-P and O-S groups with respect to member sentiments, cooperation climate, propensity to share information, and innovation outcomes, the F-S group did not attain a substantial advantage over the other groups in these domains. The efficacy of offline cooperation with virtual sharing tools in mitigating the adverse impact of heightened team virtuality on innovation outcomes is well-documented; however, the superiority of such methods over other virtual teams in terms of innovation remains to be substantiated through further experimentation.

This study demonstrates that design studio teams that adopt offline communication and an online sharing platform exhibit a higher level of creativity than traditional design studio teams with offline communication only. Furthermore, these teams demonstrate a better innovation climate and a stronger willingness to share information among members than design studio teams with online communication and the use of shared tools. The findings underscore the efficacy of a hybrid DSE model, which has the capacity to leverage the strengths inherent in both traditional and virtual studios [18]. In the process of DSE virtualization, the integration of suitable virtual communication and collaborative creation within traditional design studios is identified as a pivotal factor in enhancing innovation and performance.

7. Conclusion

7.1. Contribution and Implications

Design Studio Education (DSE) is a well-established pedagogy that cultivates innovative thinking, collaboration, effective communication, and practical skills. With the increasing integration of virtual workspaces, DSE can adopt more flexible team structures to support diverse collaborative models.

This study investigated design studio teams with varying degrees of virtuality in the context of a smart glove design project. The findings indicate that combining face-to-face communication with virtual shared work platforms enhances the innovation climate, fosters collaboration, and maximizes students’ creativity and perspective-taking. Virtual tools alone can support creative output, but maintaining opportunities for real-world interaction is essential for trust-building and information sharing among team members.

These results have important implications for design education. First, educators should carefully integrate virtual tools into studio practices to balance efficiency, creativity, and team cohesion. Second, fostering positive emotions and peer support in virtual environments is critical to sustaining engagement and innovation. Finally, the hybrid DSE model demonstrates the potential to leverage the strengths of both physical and virtual studios, providing a roadmap for future design education in increasingly digital contexts.

7.2. Limitations

It should still be noted that this study has some limitations. First, the sample size was small, limiting the generalizability of the findings. Second, the design project used—a smart glove—was relatively simple; more complex or long-term projects may reveal different impacts of virtuality on DSE. Third, participant diversity was limited, with students from similar academic and cultural backgrounds; cross-cultural or globally distributed teams may experience stronger effects of virtuality.

Future research should replicate the study with larger and more diverse samples, explore projects of varying complexity, and examine long-term virtual DSE practices. Additionally, investigating strategies to mitigate the negative effects of virtuality—such as enhancing informal communication, trust-building mechanisms, and digital collaboration training—could further optimize hybrid DSE models for global and interdisciplinary contexts.

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