A PRELIMINARY STUDY ON MULTIDISCIPLINARY DESIGN FRAMEWORK IN A VIRTUAL REALITY LEARNING ENVIRONMENT

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ABSTRACT

This article presents a preliminary study on the effectiveness of the multidisciplinary design framework (MDF) for teaching and learning in a Virtual Reality Learning Environment (VRLE). The aim of the study was to investigate the students' learning experiences with fully remote multidisciplinary groups, practicing collaborative design in a VRLE. The objective was to introduce and implement a synchronous multidisciplinary design teaching and learning engagement framework with asynchronous online documentation that manages and evaluates evidence of learning outcomes. This study employed a sequential explanatory mixed method research on a quasi-experiment involving 30 undergraduate students from the creative media specializations in collaboration with 39 other students from the business, computing, communication, and product design degree students over a 14- weeks duration. Students were surveyed using online questionnaires, interviews, and observations by the module facilitator for the quantitative and qualitative data collection. A triangulation protocol was used for the convergence coding of three data sets. Results revealed that there were 85% students scoring grade A's as compared to 69.3% from the previous cohort that was without the framework and VRLE support. Overall, the students' commented that the multidisciplinary design collaboration was beneficial, realizing the advantage of collaborating to merge various skill sets and knowledge to solve problems that couldn't be solved alone. The study's finding implied that the MDF effectively achieved the teaching and learning outcomes and could be applied to all higher education multidisciplinary collaborations in a VRLE.

KEYWORDS

multidisciplinary design, virtual reality learning environment, education technology

1. INTRODUCTION

The world is confronted with a plethora of pressing problems that interconnects social and cultural sectors such as poverty, sustainability, exploitation, discrimination, oppression, capitalist ideology, globalization, and the free market. Such ill-defined and difficult problems are indeterminate in scope and scale. To comprehend and solve such complex problems, deeper perspectives and interaction of disciplines is crucially needed to create novel collaborative solutions beyond conventional protocols. The multi-faceted collaboration of varying disciplines provides the broader scope for the integration of diverse knowledge that affords comprehension of complex problematics [1].

Innovation, entrepreneurship, and business strategy scholars have been focusing on Design Thinking as a viable approach to solving 'wicked problems' with disciplined creativity and nonlinear problem- solving methods [2][3][4]. The World Economic Forum (WEF) 'The Future of Jobs' 2020 stated that future work skills by 2025 requires proficiencies and abilities in Critical

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thinking and analysis, Problem-solving, Self- management, Working with people, Management and communication of activities, Technology use and development, Core literacies and Physical abilities [5].

Tim Brown, the Chief Executive Officer of IDEO who brought Design Thinking to the business world opines that Design Thinking or mindset provides a methodology of modes that stresses on the human- centred approach to innovation. The methodology utilizes the designer's toolkit to integrate the needs of people, the possibilities of technology and the requirements for business success [6].

However, the Design Thinking methodology alone is deficient in creating a design learning framework that would inculcate students with the desired 4IR skills. Lecturers or teaching and learning facilitators need a framework that would align the students' learning goals with engaging and motivating learning activities in immersive learning environments that affords integrated assessments. The immersive learning environment ought to be designed based on pedagogical priorities than technology to derive effective learning benefits or outcomes [7].

Various research studies have revealed that Virtual Reality (VR) based education technology are indeed effective in providing engaging and motivational learning experiences compared with personal computers and tablets. Researchers from the University of Maryland found that VR's immersive 'presence' helped learners focus better [8] revealed that well designed VR simulations motivate learners to put in extra effort to learn new material because of the enjoyment in learning. Other researchers found that VR enhanced learning media increases ethical efficiency amongst learners by increasing their self-efficacy [9][10]. Nonetheless, the design of Virtual Learning Environments (VLE) should prioritize the pedagogical affordances that is guided by learning design systems and not technological advancements [11].

This research study aimed to create a teaching and learning framework that combines the Design Thinking methodology with Project-based Learning pedagogy to form a Learning Design Sequence that integrates formative and summative assessments of and for learning within a VRLE by Selander's LDS [12]. The MDF will be used to investigate the students' learning experiences with fully remote multidisciplinary groups, practicing collaborative design in a VRLE, with the objective to introduce and implement a synchronous multidisciplinary design teaching and learning engagement framework with asynchronous online documentation that manages and evaluates evidence of learning outcomes.

This article starts with a literature review on the design process and learning design sequences and follows with the design thinking model involved in the study. Next, the article describes a sequential explanatory mixed method follows by the qualitative thematic analysis.the data analysis section explains on the validation of the framework and assessment rubrics. a pilot study was also described in in this article which later shows the MDF influence on the final assessment performance and the correlation between the MDF and the 4IRSkills. Next, students' perception of the MDF learning experience are also being described. The article ends with discussion and conclusions sections.

2. LITERATURE REVIEW

The scope of the literature review covers the design process and learning design sequences that combines with the Design Thinking methodology and the pedagogies of Project-based and Situated Learning to form the design of the MDF. The review ends with the VRLE design, based on the defining features or characteristics of a blended reality collaborative environment with Miro and Spatial.io.

2.1. Design Process

Design processes are essential practices where designers 'make meaning' of their works. The misconception of innovation where fully developed ground-breaking ideas leaps out from genius minds in 'Eureka' moments, is nothing but myths. Most innovations are produced from rigour and discipline [13].From the various design processes in practice, the similarities are found in the divergent and convergent modes of thinking, the two different sides of the same coin in problem-solving [14][15]. Design practitioners adopts an iterative rotation of divergent and convergent thinking as mode shifters in a non-linear fashion of the design process [16]. Though the design process is synonymous with problem- solving, the process lacked details for theoretical mapping of teaching and learning constructive alignment.

2.2. Learning Design Sequence

A creative learning process by [17] was combined with Selander's LDS, forming a design studio learning framework emphasizing on user-centred design process. The design studio learning framework was created to support course designers and facilitators for effective learning design. The framework provided a systematic tool for the facilitators to increase the design challenges' difficulty level for the students to develop confidence in tackling open ended complex and strategic design problems. The approach was designed to facilitate critical thinking, experience-based knowledge construction and self-directness when designing for current and future devices and targeted platforms.

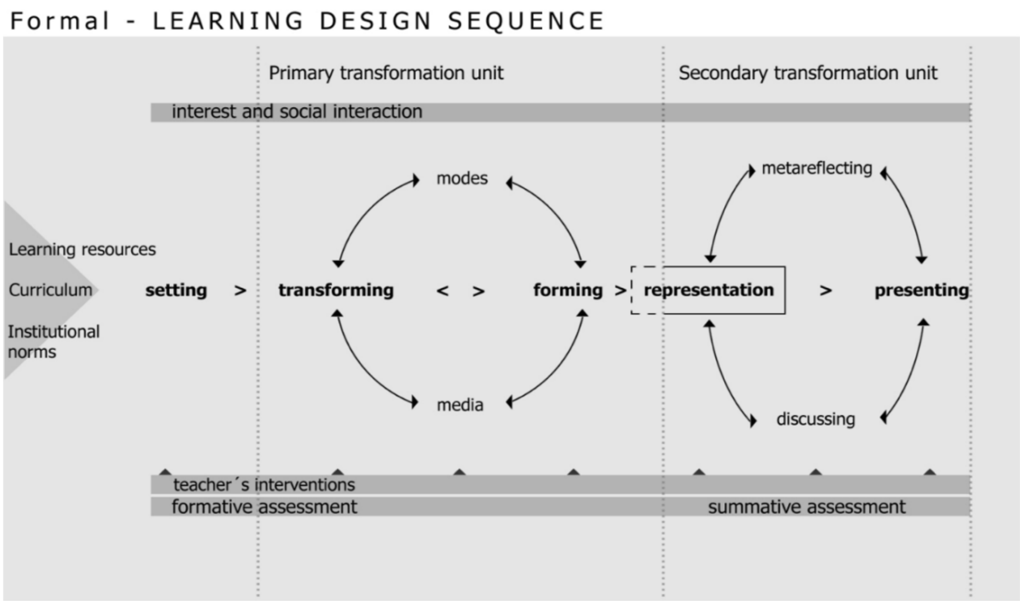

Figure 1. Learning Design Sequence's transformation cycles [12].

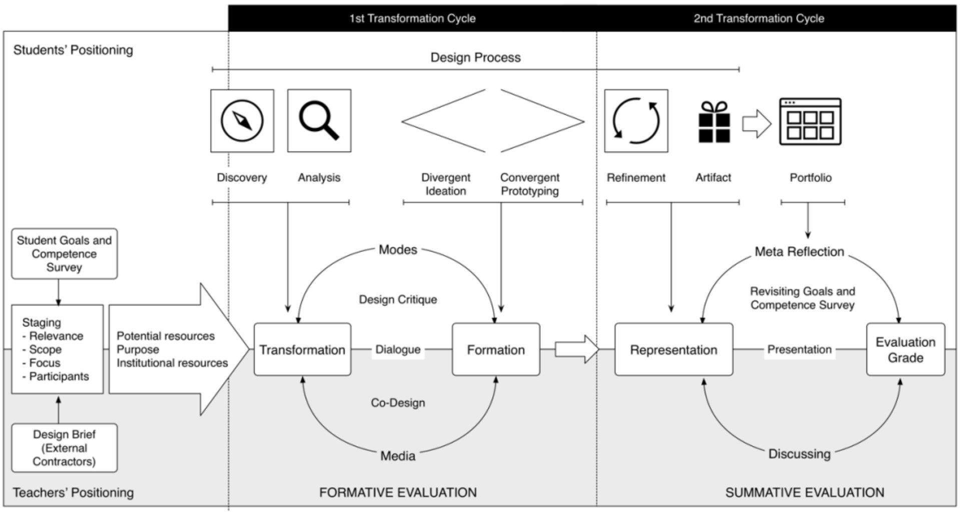

Figure 2. Digital design process in relation to transformational cycles in the design studio learning environment [17].

Wärnestål'sframework, however, did not map and measure the learning activities, the students' artefact quality or standard with the intended learning outcomes. Therefore, the constructive alignment was not addressed by the framework. Wärnestål's study only revealed the students and teachers' reflections of their perceived learning experiences, lacking student's performance data. Without considering the students' assessment results, the reliability and effectiveness of the framework in achieving the learning outcomes is questionable.

2.3. Design Thinking Model

Design Thinking from a pedagogical perspective, is deeply rooted in the social constructivism learning theory [18] with learning and development activities scaffolded within a collaborative peer or expert guided environment. The range between a student's introduction as an apprentice or novice till the master or expert level is called the Zone of Proximal Development (ZPD). The student's learning and development journey within the ZPD matches the Design Thinking phases of Empathy, Define, Ideation, Prototype and Testing. The social constructivist Vygotsky stressed on social interactions as vital to strengthening the learning process. Students learn more effectively when they are posited in a conducive socially connected learning environment that enables concept and idea internalization [4]. Design Thinkers practices engagement in deductive reasoning with the exploration of unbiased and sketchy answers. This in-depth analysis internalizes ideas and concepts like social constructivism [19].

One of the most well-known Design Thinking model is from the Stanford University's Hasso Plattner Institute of Design, or d.school version [20]. Stanford's d.school had been teaching Design Thinking as a formal method since 2005. The approach is a user-centredproblem-solving methodology that is driven by human-centred empathy with five distinct and iterative stages or phases of Design Thinking. Due to the interplay of convergent and divergent thinking processes, the five stages are not sequential by nature. In fact, there is no specific sequence as the processes could be parallel or iteratively repetitive. Due to the non-sequential flow, these stages or phases should be represented as modes rather than sequential steps. The free-flowing iterative modes are versatile and suitable for collaborative multidisciplinary design practices that often shuffles back and forth in the design process, responding to the targeted audiences and users' thoughts and feelings. The Design Thinking methodology is discipline agnostic and empowers students to build their creative confidence, transforming their abilities with intrinsic motivation and maturing the entrepreneurial mindset and the belief in making a difference for the world.

2.4. Project-Based Learning

The multidisciplinary design project collaboration in this study adopted the Project-based Learning (PjBL) pedagogy, modelled after the Stanford University's PBL Lab of problem based, project centred activities with client-based re-engineering processes. The process merges people from various disciplines propagating cross-disciplinary collaborative teamwork across distributed locations. PjBL has been used widely to facilitate transdisciplinary design teaching and learning where learners are presented with complex problems that needs collaborative efforts from multiple and relevant disciplines, to pull resources, knowledge, and skills to create the appropriate solution [21][22][23]. The learner-centred approach promotes active learning where learners are posited in real-life scenarios of practical problems contrasting the conventional passive learning where learners are forced to learn from lectures with 'sage on the stage' academicians [24]. The learner-centeredness of PjBL, inculcates autonomous learning by motivating learners to form and practice collaborative peer directed problem solving via 'learn by doing' activities ([25][26]. This inquiry driven intrinsic learning approach enable learners to demonstrate increased engagement with the disciplines' insights, gaining confidence and enhanced capacities when solving real-world problems [27]. The learners' level of reflections, new knowledge construction and metacognition are improved, equipping them for cross-context collaboration, peer-to-peer learning engagement and communication with global perspectives. The key identifying characteristic of the learner-centred problem-solving oriented pedagogy, makes PjBL the preferred alternative to curriculum-oriented pedagogies [28][29].

2.5. Studio-Based Learning

A learning model that originated form the 19th century École des Beaux-Arts atelier of learning from master artists in art studios has been adopted widely in architecture, design education and even in natural sciences, informatics, and Human-Computer Interaction (HCI) practices [30]. The Bauhaus period (1919 to 1933), however saw a shift of focus from skill attainment to learning how to design, while working on design works with conceptual frameworks [31]. Studio-based Learning (SBL) agrees with transformative learning theories such as Experiential Learning [32] and Symbolic Interactionism [33]. SBL learners practice analysis, integration and critique sessions with peers and facilitators to produce new knowledge advancing beyond the lecturers or teachers' level. The SBL premise is a multipurpose and flexible space for teaching and learning activities such as demonstrations of practice, workshops, lectures, and collaborative works, in formal and informal regulated sessions of discussions with peers and facilitators. The sessions facilitate ideation, design, creation, and the making of prototypes in peer reviewed discussions supported by facilitators and industry experts [14]. The iterative design practice of SBL provides for procedural knowledge development as learners practice creating artefacts with reflection-in-action and reflection-on-action [34]. The cyclical procedural competencies and knowledge creation while experimenting and creating artefacts, is coherent with the Kolb's Experiential Learning four cyclic stages of learning [32]. SBL also draws similarities from social constructivism learning theory where social interaction is a means for learning through dialogue with critique sessions and collaborative design practice amongst peers and facilitators. Incidentally, these features, taken resembles professional design practice of inquiry-driven, experimental problem-solving with multidisciplinary collaborative design amongst peers and external partners. SBL was adopted for this study in combination with the PjBL to achieve the situated learning aims for a studio-based VRLE simulation.

2.6. Virtual Reality Learning Environment (VRLE)

The constructivism learning theory where knowledge is constructed by learners rather than learned passively from teacher or lecturer-centred learning, is strongly advocated by the VRLEs [35]. The VRLEs when designed with the pedagogy as priority, affords peer learning activities of proactive peer-support; and these activities produce high learning impact with positive learning mood creation through engagements, motivations and emotional upbuilding in learners. The feel-good factor when learning is a vital aspect that is often discarded when chasing for higher test scores [36]. A well-known strength of VR in producing the sense of presence, an immersive feeling of actually ‘being there’; is highly suitable for the creation of appropriate simulation of studio- based and experiential learning.

3. Research Methodology

3.1. Sequential Explanatory Mixed Method

A sequential explanatory mixed method research was implemented for this study that included the data collection from quantitative online questionnaires and analysis which informed the design of the semi- structured interview questions, followed by the qualitative thematic analysis [37].

Additional observational data was gathered by the researcher to complement the students’ produced artefacts. The sequential explanatory mixed method had a two-fold approach where the qualitative results were used to explain and interpret the quantitative findings of the study. The data gathering consisted of the pre-test and post-test quasi-experiment on the control and treatment groups to establish the comparison and contrasting effect of the MDF with VRLE. The study’s sampling choice is purposive as the cohort of students enrolling for the experiment’s module was not predetermined and neither could it be controlled. Therefore, the quasi-experimental approach was selected as the respondents’ randomized selection process was not possible [38][39]. With the initial quantitative findings confirmed, the result was used to design the interview questions for the qualitative semi-structured interview phase. The interview results through thematic analysis would then be used to explain the online survey data, triangulated with the lecturer’s observational notes. The thematic analysis was conducted with the transcribing and the generating of nodes in the NVivo software. The identified key and sub-themes were then used for the triangulation comparison with the online and observational data. To ensure reliability, the triangulation protocol of utilizing data collection from multiple sources and from differing times was practiced [40]. A triangulation protocol was applied to interpret and combined the findings from the quantitative and qualitative data [41].

3.2. Data Collection

This research study was conducted in a mixed method sequential explanatory approach which involved two data collection phases, with the initial quantitative data collection and analysis that informed the design of the qualitative data collection. The qualitative data collection consisted of the semi-structured interviews, researcher observations and the students’ submitted artefacts; were analysed to infer and interpret the quantitative data. The sequential data gathering and analysis of both the quantitative and qualitative data demonstrates the complementary benefits of analysing both data types to help with a deeper understanding of the problem more efficiently.

The quantitative data collection in the form of online questionnaires was conducted as pre-test, before the students were given the 'Creative Brief' and followed with the post-test after the 'Project Submission' date for both the control group (G1) and treatment group (G2). These questionnaires were designed with the five-point Likert scale (strongly agree, agree, undecided, disagree, strongly disagree). The questions were created to collect the students' general information, technology usage preferences (VR competencies) and their perceptions about the design process (Design Thinking) and the collaborative transdisciplinary design practice (Collaboration in VRLE).

The qualitative data from the semi-structured interviews were conducted on ten randomly selected students at two different phases, beginning and the semester end for both the control and treatment groups. The interview questions were informed by the quantitative data findings, to gain in-depth understanding of each student interviewee's response to the MDF with VRLE.

The first semi-structured interview was conducted right after the students' completed their 'Proposal Presentation' while the second interview session was conducted after the students' 'Project Submission' date for the control group. The treatment group's first semi-structured interview was conducted after the students completed the 'Defining the Problem' phase while the second interview was conducted after the students' 'Project Submission' phase. The two separate interview sessions allowed the students to share their learning experience during and after the design process had ended, for both the control and treatment groups. The comparison between the interview data sets would provide insights on the students' differing learning experiences as a result of the MDF in VRLE.

Participant artefacts in the form of students' final submission works including the progressive artefacts that were produced during the semester, was assessed using the Taylor's University Graduate Capabilities Rubric (TGCR) which was mapped with the 4IR Workforce Skills (4IRSkills). The comparison of the final assessments between the control and treatment groups would be used for correlation analysis.

The final data set for the triangulation protocol would be the researcher's observations which was gathered throughout the students' design process duration, which comprises of students' recorded actions in Miro, Spatial.io, behaviours as individuals and as group members between the control and treatment groups, as well as the students' individual reflection blogs.

4. DATA ANALYSIS

4.1. Validation of the Framework and Assessment Rubrics

The validation of the MDF design and the mapping of the TGCs with 4IRSkills was conducted with a two-round Fuzzy Delphi Method (FDM) of eight experts on the first round and five experts for the second round. After two-round of FDM, all the construct's items were agreed upon by all experts as all three triangulation conditions were met ($d \leq 0.2$), and the percentage of consensus were all above 75% and the defuzzification cut were all above the 0.5 value. The FDM results therefore, confirmed that the MDF and the final assessment rubrics are valid for the quasi-experiment.

4.2. The Pilot Study

To ascertain the reliability of the data gathering instruments, a pilot study was conducted on the control and treatment groups over two different semesters. For the control group, the Design

Process and Design Collaboration instruments were tested and for the treatment group, the VRLE Representational Fidelity and VRLE Learner Interaction instruments were tested, as shown in Table 1. The pilot study's results on the control group's instruments showed a score of 0.82 for Cronbach's Alpha and the treatment group instruments scored 0.91, both higher than the 0.70 threshold. Therefore, the tested instruments were all reliable and no items were required to be removed.

Table 1. Data gathering instruments and the referenced models.

Instruments	Model
Design Process	• Study on the Learning Effectiveness of Stanford Design Thinking in Integrated Design Education [42]
Design Collaboration	• How can Design Thinking promote entrepreneurship in young people? [43]
VRLE Representational Fidelity	• Presence, memory and interaction in virtual environments [45] • How does desktop virtual reality enhance learning outcomes? A structural equation modelling approach [46] • What are the learning affordances of 3"D virtual environments? [47]
VRLE Learner Interaction	• A structural equation modelling investigation of the emotional value of immersive virtual reality in education [48] • A new way of teaching business ethics: The evaluation of virtual reality-based learning media [9]

4.3. Sample

The Control G1 and Treatment G2 groups were formed from the purposive sampling of 30 students over two differing semesters. For both the groups, the students came from four different disciplines.

4.4. The MDF Influence on the Final Assessment Performance

A descriptive statistic test was conducted on the mean score comparison between the Control group G1 and Treatment group G2. The Control Group G1 and Treatment Group G2 final assessment marks' descriptive statistics analysis showed the mean scores of the Treatment Group G2 scoring higher ($M=80.3$, $SD=4.04$) than the Control Group G1 ($M=70.7$, $SD=9.67$).

A normality test for the control and treatment group's final assessment marks was conducted and the Shapiro-Wilk test showed a significant departure from normality for both the Control group G1 and Treatment group G2, $W(30)=0.83$, $p=0.001$ and $W(30)=0.87$, $p=0.001$ respectively. The non-normality confirmation required the non-parametric Mann-Whitney U test, to determine the significant difference between the two independent groups' final marks.

The Shapiro-Wilk test showed a significant departure from normality for both the Control group G1 and Treatment group G2, $W(30)=0.83$, $p=0.001$ and $W(30)=0.87$, $p=0.001$ respectively. Due to the evidence of non-normality, a non-parametric Mann-Whitney U test was conducted to determine the significant difference between the two independent groups' final marks. The inferential statistic for the control and treatment group's final assessment marks was conducted to confirm significance of the MDF with VRLE on the students' final assessment performance.
There was significant difference between the Control group G1 and Treatment group G2 students' final assessment marks according to the Mann-Whitney test, $U=171.0$, $p=0.001$. This

result demonstrated the evidence improved students' final assessment performance due to the applied MDF with VRLE, where the treatment group's mean score 80.3 was higher than 70.7 to the control group.

4.5. Correlation between the MDF and the 4IRSkills

The Levene's test was conducted to test the homogeneity of variances for equality, on the Design Learning (Design Process and Collaborative Learning) and VRLE (Representational Fidelity and Learner Interaction) learning experiences. This test was used to indicate if there was any variances violation for all four modes of learning experiences. This was followed by the correlation and effect investigation with the mean score of the Design Learning and VRLE using a one-way ANOVA test. Thereafter, the Tukey post-hoc comparisons were used to reveal which pairing within the group is significantly different. Lastly, to determine the Treatment Groups G2's relationship strength with the students' final assessment marks, the Pearson correlation coefficient test was performed.

The was equal variances for Design Learning and VRLE from Levene's test, $F(3,116) = 2.35$, $p = 0.08$. The four groups (Design Process and Collaborative Learning, Representational Fidelity, and Learner Interaction) have equal variances and the homogeneity of variances was met, $p(.08) > \alpha(.05)$, which indicated non-significance and the one-way ANOVA can then be conducted.

The ANOVA test revealed a statistically significant difference in between the four groups, ($F(3,116) = 20.7$, $p = .001$). To determine which specific pairs of means are significantly different, a Tukey post hoc was conducted.

The Tukey post hoc test revealed that the Design Process is not significantly different from Design Collaboration (p = 0.511, 95% C.I. = [-0.6341, 0.194]) but is different from VRLE Representational Fidelity (p = 0.001, 95% C.I. = [0.273, 1.101]) and VRLE Learner Interaction (p = 0.001, 95% C.I. = [0.412, 1.240]). The Design Collaboration is significantly different from VRLE Representational Fidelity (p = 0.001, 95% C.I. = [0.493, 1.321]) and VRLE Learner Interaction (p = 0.001, 95% C.I. = [0.632, 1.460]), whereas the VRLE Representational Fidelity is not significantly different from the VRLE Learner Interaction (p = 0.818, 95% C.I. = [-0.275, 0.553]) but is significantly different from the Design Process (p = 0.001, 95% C.I. = [-1.101, -0.273]) and the Design Collaboration (p = 0.001, 95% C.I. = [-1.321, -0.493]).

The Tukey post-hoc test was conducted on the homogenous subsets of Design Learning (Design Process and Design Collaboration) and VRLE (Learner Interaction and Representational Fidelity); to determine the difference between them.

The Design Process and Design Collaboration belonged together as a subset while the VRLE Learner Interaction and VRLE Representational Fidelity was the other subset. Therefore, the VRLE subset was significantly different from the Design Learning subset. The Design Process and Design Collaboration was considered with high student perception scores and the VRLE Learner Interaction and VRLE Representational Fidelity, the lower student perception score subset. The score within the two groups were not significantly different from each other.

To determine the effect size, another One-way ANOVA test was conducted on the Design Process, Design Collaboration, VRLE Learner Interaction and Representational Fidelity experience for the Treatment Group G2.

The Partial Eta Squared test revealed the difference in effect size of 35% (0.349) on the variability in the Design Learning students' experience due to the difference between the four learning experiences as grouped in the two subsets. According to Cohen (1992), this 35% effects size is considered large between the two subsets with the subset of Design Process and Design Collaboration producing 35% higher student perceived satisfaction than VRLE Learner Interaction and VRLE Representational Fidelity [49].

The Pearson's correlation coefficient test was the final test to ascertain the Treatment Group G2's relationship strength with the students' final assessment marks. Both the subsets' pairings of Design Learning (Design Process and Design Collaboration) and VRLE (Learner Interaction and VRLE Representational Fidelity) was tested.

A Pearson correlation coefficient test was conducted to assess the relationship between the Design Learning (Design Process and Collaboration) and the final assessment marks (4IRSkills). There was a strong, positive correlation between the two variables, $r = .949$, $N = 30$; the relationship was significant ($p = .001$). Increases in Design Learning scores were correlated with increases in the final assessment marks.

A Pearson correlation coefficient test was conducted again to assess the relationship between the VRLE (Representational Fidelity and Learner Interaction) and the final assessment marks (4IRSkills). There was a weak, negative correlation between the two variables, $r = .033$, $N = 30$; the relationship was non-significant ($p = .862$). Increases in VRLE scores were not correlated with increases in the final assessment marks.

4.6. Students' Perception of the MDF Learning Experience

A thematic analysis was implemented based on the six-steps by Braun and Clarke[50]. Random sampling (n=10) was conducted on the Control group G1 and Treatment group G2 students for the semi-structured interview sessions. Each student was interviewed twice, once on the 5th week and another on the 14th week. Deductive coding was practiced with the informed data obtained from the quantitative analysis forming the theoretical lens of the mixed-method sequential explanatory approach [51][37]. The generated codes were organized into a Codebook which served as the foundation for theme generation.

The triangulation protocol with the 12 key findings were derived across the three data sets and the level of agreement in the Convergent Coding Matrix table. The findings revealed marginal agreements of 'Agreements' and 'Partial agreements' coding. No 'Disagreement' codes from the triangulation emerged but there were two 'Silence' codes found in the quantitative online survey as these two items on improved organization of design practice and increased time consumption were not tested but commented on positively in the semi-structured interviews and facilitator's observations. The other two 'silence' codes were from the students' understanding of constructive alignment as evaluated in the online survey but none of them mentioned about this alignment in the semi-structured interviews and the facilitator's observations. The final 'silence' code appeared in the semi-structured interview about the ability to monitor learning progression with online feedback, assessments, and virtual consultations, whereas students have a positive review of this item in the online survey and the facilitator's observations.

5. DISCUSSION

The one-way ANOVA correlation and effect investigation on the mean scores of the Design Learning (Design Process and Collaboration) and VRLE (VRLE Representational Fidelity and Learner Interaction) subsets, revealed that there was a statistically significant difference in between the Design Process, Collaboration, VRLE Representational Fidelity and Learner

Interaction groups. A Tukey post hoc test was conducted to determine which specific pairs of means were significantly different as the one-way ANOVA test could not determine which were significantly different.

The Tukey post hoc test revealed that Design Process was not significantly different from Design Collaboration but was different from VRLE Representational Fidelity and VRLE Learner Interaction. The Design Collaboration was also significantly different from VRLE Representational Fidelity and VRLE Learner Interaction, whereas VRLE Representational Fidelity was not significantly different from VRLE Learner Interaction but was different from Design Process and Design Collaboration. As the VRLE Learner Interaction and VRLE Representational Fidelity learning experiences seem to belong together as the same subset and the Design Process and Design Collaboration belonged together as the other subset therefore, the VRLE Learner Interaction and VRLE Representational Fidelity subset was significantly different from the Design Process and Design Collaboration subset.

The mean score of students' learning perception of the Design Process and Design Collaboration was found to be higher than the VRLE Learner Interaction and VRLE Representational Fidelity. The reason for this difference was due to the lack of immersion and engagement for the VRLE learning experience as it was presented on a Desktop VR platform and not with the HMD.

The Partial Eta Squared test was conducted to determine the differences' effect size between the Design Process and Design Collaboration subset and the VRLE Learner Interaction and Representational Fidelity subset. Using measurement in [51][52], the results indicatea large effect size of 35%, which meant that students perceived 35% higher satisfaction for Design Process and Design Collaboration than VRLE Learner Interaction and VRLE Representational Fidelity.

A Pearson's correlation coefficient test was conducted to determine the Treatment Group G2's relationship strength with the students' final assessment marks. The results showed a strong, positive correlation between Design Learning (Design Process and Collaboration) and the final assessment marks (4IRSkills); where the increases in Design Learning scores were correlated with increases in the final assessment marks. In contrast, there was a weak, negative correlation between VRLE (Representational Fidelity and Learner Interaction) and the final assessment marks (4IRSkills), where increases in VRLE scores were not correlated with increases in the final assessment marks.

Therefore, the confirmation of correlation between the MDF with VRLE and the creation of 4IRSkills, with the Design Process and Collaboration variables showed a 35% positive correlation strength with the increase of final assessment marks (4IRSkills); but a negative correlation between the between VRLE (Representational Fidelity and Learner Interaction) and the final assessment marks (4IRSkills). Overall, the triangulation protocol showed marginal positive learning experience gained from the MDF with VRLE that is embedded with Design Thinking practice.

The semi-structured interviews' thematic analysis on the control and treatment group students revealed that the MDF with VRLE produced realizations of a systematic approach and confidence in the design process amongst the treatment group students as compared to the control group students. The treatment group also realized the benefits of collaborating across disciplines with the MDF to produce outcomes that are greater in scope and depth, while meeting industry needs. The triangulation of the students' reflection blogs and the final assessments was coherent with the semi-structured interview findings. The triangulation Convergent Coding Scheme also revealed that there were marginal agreements on the key findings from the inferential statistics, thematic analysis, and the facilitator's observations.

6. CONCLUSIONS

The findings of this research study confirmed that there was indeed significant positive correlation between the MDF with VRLE and the attainment of 4IRSkills. This result contributes to the understanding of how transdisciplinary groups of undergraduate students could collaborate online effectively to achieve the intended learning outcomes of attaining 4IRSkills. The empirical evidence demonstrated that the MDF as an effective Desktop VRLE solution for academicians, curriculum developers and university policy makers.

The small sample group which posed a generalization constraint on validity and reliability, was the limitation of this study. Added to this, was the lack of consistency in the student groups' workload, project challenge complexities, group dynamics, knowledge, and skills competencies amongst the group members. The dissimilarities could have posed a distortion in the experiment results as the measurement constructs were focussed on students perceived learning experience from the design process and the collaboration practices. The students learning experience with the MDF in a VRLE was also limited due to the inaccessibility of HMD devices, that could have produced much higher levels of immersion and presence. Instead, the Desktop VR that was used produced a low satisfaction rate amongst the students.

For future investigations, the MDF and pedagogy model could be generalized to wider student samples and implemented on different subject matters or disciplines that are relevant to online remote VR. Perhaps different core disciplines that involves collaborative design projects with oversea university modules could be investigated. The research could delve deeper into the variables related to individual student differences such as learner behaviour and social-cultural contexts as different cultural backgrounds from different geographical locales could influence the learning of transdisciplinary design collaboration within a VRLE.

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