The influence of immersion and presence in early stage engineering designing and building

The Influence of Immersion and Presence in Early Stage Engineering Designing and Building

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This paper explores the role of a designer's sense of engagement in early stage design. In the field of virtual reality, presence and immersion are standard measures of an individual's sense of engagement and involvement in an activity. High levels of presence might indicate that the designer is highly focused on the work. The central research question is: Do designers who are more engaged in design activity, as measured by presence and immersive tendency questionnaires, produce better designs? An experiment was conducted to assess presence and immersive tendencies within the context of a hands-on, open-ended design-and-build activity. Results indicate that designers' sense of immersion and presence ranged widely as well as their sense of frustration and calmness while performing the design activity. It was found that higher levels of presence correlated with either high design performance or, surprisingly, low design performance. Lower levels of presence correlated with average design performance. No correlations were found between immersive tendency and design performance. This study suggests that some level of presence can be linked with better design, and implies that level of presence might serve as an indicator of performance and learning in similar design-and-build activities.

Introduction

Designers may employ a range of tools and techniques while involved in key activities in early stage design such as generating, selecting, and evaluating concepts. A range of tools may be used to explore and evaluate ideas in order to drive the design process forward, including sketching of possible design concepts [1-6] and the building of prototypes of design alternatives [7-14]. In particular, the process of constructing physical prototypes of a design idea can uncover important design issues [15] that may not be apparent from a 2D representation such as a sketch. The studies referenced above demonstrate the value of tools for design, but don't consider how the designer personally experiences the process of designing. Some have noted that the hands-on experience of manipulating materials while building a prototype, including fabrication of components and assembly, provides the designer with an opportunity to reflect and interact with a design while exploring and evaluating the space of design concepts [16]. Indeed, the act of creating a design through sketching has been described as a "dialogue" with paper [17], suggesting that there is some level of engagement between the designer and the act of sketching.

In studies of creativity, Csikszentmihalyi more generally discussed the notion of "flow" that experts experience while absorbed performing an activity that allows them to lose sense of time [18]. Flow is defined to be the feeling of full control over the activity [18]. It is characterized by concentrating and focusing of an activity, being intensely involved with clear understanding of goals and feedback. People in flow have a distorted sense of time. While presence is often described as immersion into a virtual environment (VE), flow is referred to an experience of immersion into a certain activity [18]. Flow evaluated on task characteristics.

This paper seeks to better understand how design-and-build activity may be linked with the designer's sense of engagement while creating the design, and with eventual design outcome. Design-and-build activity requires a designer to manually assemble, join, and test a physical externalization of a design. To assess designer engagement, we turn to *immersion* and *presence*, metrics borrowed from the field of virtual reality. There is no one universally agreed upon definition of presence, though two commonly cited in the literature define presence as the extent to which an individual has the feeling of being engaged in the moment [19-21] or the "experience of being in one place or environment, even when one is physically situated in another" [22]. For example, a person playing a video game set on the planet Mars might have the sensation of being on Mars, though in reality they are physically located in their living room. Presence, in particular, has been shown to have some positive correlation with performance on virtual tasks [23], and this explores if there is a similar effect on real world design tasks. Immersive tendency also relates to the sense of involvement in an activity but is considered an individual trait and relates to the tendency to behave playfully and to become involved in a continuous stream of stimuli [24]. For example, one person reading a book might become so deeply engaged, or "in the moment", that he or she loses awareness of their surroundings. However, another person reading might not experience such immersion. This deep engagement with a given task is very much dependent on the individual. Immersion can lead to presence, which is the user's sense of being in the virtual environment. Both presence and immersion are components relating to the sense of being involved in a task.

The research questions this paper explores is:

1. *What is the nature of immersion and presence in the context of early stage design-and-build activities?* How are immersive tendencies and presence linked to the design process? Presence and immersion are important to virtual reality applications and measure how well a person "responds" to the virtual environment and we believe these tendencies have relevance to how designers may perform in the real world. Engineering design has developed its own criteria to gather information during the design process. If we assume that presence and immersion are related to a notion of flow, can it be that designers experience a similar feeling while designing? Verlinden *et* al. [25] have studied the use of augmented virtual reality systems to support design prototyping, but in this paper we consider presence and immersive tendencies of the individual designer, rather than as a virtual reality technology.

2. *Do immersive tendencies correlate with better design?* Does more engagement mean better performance? *Not* being engaged in an activity would seem to mean poorer performance, but is the converse true?

In this study, we assess participants' levels of presence and immersion during the process of hands-on designing and prototyping activity in the real (rather than virtual) world. The performance of the resulting designs is then correlated with presence, immersion and other factors.

Background

Presence and immersive tendency in the virtual world

Presence and immersive tendency have been studied extensively in the field of virtual reality [26]. In order for virtual reality to seem real, the environment must respond authentically to the user's actions. Virtual reality technology allows the user to be present in a virtual world and to be mentally immersed while the virtual reality system senses the user's position and actions and responds to one or more of the user's senses. The key elements of the virtual reality experience are the virtual world, immersion, sensory feedback and interactivity.

Presence can be a major factor that determines the quality and success of a virtual environment implementation. Witmer and Singer [23] suggest several factors such as selective attention, involvement and immersive response as necessary to experience presence. Others identified different factors contributing to presence such as spatial presence, quality of immersion, involvement, drama, and interface awareness, exploration of virtual environment, predictability and interaction, realness [19]. However, Inkso points out that the problem with any questionnaire is that two people may have different responses in the same environment [20]. He claims the PQ measures the user's perception of system properties, rather than psychological presence [27].

The tendency to experience presence is considered a personal characteristic of the user. Witmer and Singer therefore suggested another factor in presence measurement called immersive tendency. This can be a personal tendency to be drawn into reading a book or involved in another activity. Research by Samana *et* al. [28] determined that personality traits such as empathy correlated with the experience of presence. Several studies have shown that presence tends to increase as the fidelity of a reproduction or simulation of the physical world increases. This can be done with high-resolution displays, physics simulation, sound location or other measures.

The Presence Questionnaire (PQ) has been used to compare presence in a real office environment and virtual reality office. The study found that there was no difference in presence between the two environments. The researchers then tried to explain why people felt equally present in virtual reality and "real" reality. Usoh *et* al. write, “In the real-world, since there is no doubt that the individual is present in the obvious sense, it becomes reinterpreted as the sense of involvement, the lack of isolation, perhaps the degree of comfort” [29]. The questionnaire has been criticized in the way it correlates individual scores with the sum of scores [24, 27]. However, this questionnaire was chosen for the experiment in this paper because it standardizes the information gathering process for this study.

Immersive tendency is considered a trait and relates to the tendency to behave playfully and to become involved in a continuous stream of stimuli. Witmer and Singer’s Immersive Tendencies Questionnaire (ITQ) contains 29 items [23]. For example, “How mentally alert do you feel at the present time?” tests the current “state” of the user and “Have you ever remained apprehensive or fearful long after watching a scary movie?” tests the trait. There is some interrelatedness between the PQ and the ITQ. A greater sense of immersion will produce higher levels of presence. Major components that increase the level of immersion include isolation from the physical environment, perception of self-inclusion in the virtual environment, natural modes of interaction and control, and perception of self-movement. Witmer and Singer characterize immersion as a psychological state where one perceives to be engaged by an environment that provides a continuous stream of stimuli, experiences and interactions.

Subscales for both ITQ and PQ were identified from the previous analysis by Witmer and Singer. The subscale labels are loosely based on the content of the questionnaire items in their cluster. The ITQ contains three subscales: involvement, focus and games. Subscales for the PQ include involvement, sensory fidelity, adaptation/immersion and interface quality. Other researchers have tried to qualitatively define immersion with taxonomies [30, 31], but the ITQ and PQ developed and revised by Witmer and Singer continue to be the standard in virtual reality research. Witmer *et* al. showed that the PQ and ITQ are internally consistent measures with high reliability. In several of their studies, a weak but consistent positive relation between presence and task performance in VEs was shown and individual immersive tendencies measured by the ITQ predicted presence as measured by the PQ. Witmer *et* al. reported internal consistency measures of reliability of 0.75 for ITQ and 0.81 PQ using Cronbach's Alpha. They also reported a mean score on the PQ of 98.11 ± 15.78 when tested in their VE.

These questionnaires have been used extensively to assess immersion and presence in many applications. Swindells *et* al. used presence and immersive tendencies to compare different virtual reality configurations [32]. Pausch *et* al. [33] used these questionnaires to compare a virtual reality interface with a "real" stationary monitor and a hand-based input device. Users completed a search task faster with the virtual reality setup than users with monitor and hand-held device. Banerjee *et* al. used their own modified version of the ITQ and PQ to show that virtual environments are advantageous for conceptual design reviews over traditional methods [34, 35]. Darken *et* al. used the ITQ and PQ to develop quantitative measures of attention and spatial comprehension [36].

Other studies compare the performance of multiple immersive displays and input for virtual reality applications devices [37]. Robertson *et* al. determined that head-mounted displays performance characteristics did not transfer to desktop virtual reality [38]. Stothard *et* al. used immersion and presence levels to assess mine workers in interactive training [39]. Nichols *et* al. compared the use of direct performance measures and rating scales to evaluate presence for different virtual environments [40]. Virtual reality has been used in engineering design to facilitate interaction with models, assembly prototyping and other uses. Examples of engineering design in virtual reality include hose routing planning, visualizing computational fluid dynamics, and product reviews. In assembly prototyping, it has been shown that the use of virtual environments helps users perform assembly tasks [41]. This study differs from prior work in that it considers the role of immersion and presence in the *process* of design and assembly, not as a comparison with virtual experiences.

Presence and immersive tendency in the real world

Some people experience high levels of involvement with other media than VE, such as movies, books, and video arcade games. They feel that they are part of that environment or they identify strongly with a character in a book, movie or video game. During immersion, these individuals put themselves in that character's place and experience what that character experiences. They become immersed in that character's world. A dream is another example of a high level of immersion other than a VE. Witmer *et* al. believe that both involvement and immersion are necessary for experiencing presence. Furthermore, psychology reviews suggest that humans can experience varying degrees of presence at any given time in any given physical place. This is largely dependent on how much attention is divided between the physical world and the mental world (for example, memories, daydreams and planned activities). The extent of the person's involvement in any environment and how much presence they report is dependent on how sharply they focus their attention in any given task.

No distractions were present in this study; all experiments were conducted in a room with closed doors. This is consistent with VE research, where participants are engaged in their activity, but not aware of the observers or other distractions. None of these studies include mascots or character passing by. Of course, the PQ and ITQ questionnaires are self-reporting and are a standard set of tools to evaluate users in virtual environments. The PQ and ITQ questionnaires are geared towards a task and measuring the presence while the person is doing the task.

Methods

Participants

The study involved 30 graduate and undergraduate students in a Mechanical Engineering department at a US university. The participants were solicited through email and posters. The sample population was composed of 14 females and 16 males with ages ranging from 18 to 31 years (mean of 23 years). The participants reported an average of 7 years of design experience (including both classroom and industry experience). On average, they spend 11 hours per week on design related activities while at school. In addition, the students took 5 design classes during their studies. No compensation was provided to the participants. Each participant worked individually in an isolated room. They did not have access to view other designs and the results from other participants were not divulged to any participants as this could potentially influence the design outcome.

Procedure

Each experiment consisted of three phases that, altogether, took approximately one hour to finish. During the introductory phase, participants were presented with the informed consent form and given time to ask questions and fill out the form. Users received an overview of the study. In addition, participants were asked about their age, gender, education level and duration of previous design experience. Next, they were asked to complete the ITQ, a sample of which can be seen in Table 1. The instructions asked respondents to place an ‘‘X’’ for each question in the appropriate box.

Table 1: **Sample questions from the ITQ (Rating from 1-7)**

Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?						
1	2	3	4	5	6	7
NOT OFTEN			MODERATELY OFTEN			VERY OFTEN
Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?						
1	2	3	4	5	6	7
NOT OFTEN			MODERATELY OFTEN			VERY OFTEN
How good are you at blocking out external distractions when you are involved in something?						
1	2	3	4	5	6	7
NOT GOOD			MODERATELY GOOD			VERY GOOD

The second phase was the design and building task, which is detailed in the next section. The third phase required the participants to fill out the PQ to assess how engaged participants were in the design-and-build activity. Sample questions are shown in Table 2. In addition, all participants filled out a post-completion survey (described later) to assess their experiences during the activity. Finally, participants were asked to write down how many concepts they generated in their mind before deciding on their final design.

Table 2: **Sample questions from the PQ (Rating from 1-7)**

How aware were you of events occurring in the real world around you?

1	2	3	4	5	6	7
NOT AWARE			MODERATELY AWARE			VERY AWARE

How involved were you in the building experience?

1	2	3	4	5	6	7
NOT INVOLVED			MODERATELY INVOLVED			VERY INVOLVED

Were you involved in the experimental task to the extent that you lost track of time?

1	2	3	4	5	6	7
NOT MUCH			MODERATELY			VERY MUCH

Design-and-build task

Task

Each participant was instructed to build a device to vertically displace a Ping-Pong ball as great a distance as possible. Participants were allowed to test their design throughout the given time frame. Each participant was given 30 minutes to complete the task, which was made clear in the design instruction document. Detailed instructions on the design task, including the time limit and materials available, were given in a design instruction sheet. This limit was determined through a pilot study of 3 individuals the time sufficient to finish one working design. A timer was visible to the participants at all times. An "official" measurement was made at the end of the activity, though participants were free to ask for measurement at any point during the activity.

Materials

Participants were provided with a kit of pre-fabricated components, including 72 aluminum and stainless steel components in various shapes and sizes, axles, string, rubber bands, and fasteners (Figure 1) to build their design. Pre-fabricated components were chosen for this experiment because they would not require participants to have any prior part fabrication skills. No training was given on how to build with the kit as it was assumed that participants had sufficient mechanical engineering background to do so. Participants were instructed to use a rectangular plate as the base for their devices, allowing designs to be more easily compared.

A 500 gram weight was provided to serve as an energy source. The device's mechanism had to be activated manually as specified in the design prompt. The metal pieces were purchased from Gear Educational Systems, LLC in Hanover, MA (www.geareds.com).

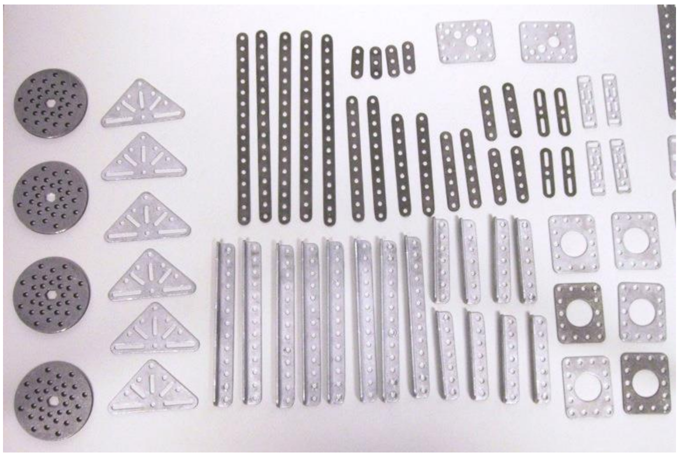

Figure 1 Sample of parts available to participants for design and assembly

A set of tools, including hex wrenches, scissors, and screwdrivers, was provided (Figure 2).

Figure 2 Tools available to participants for assembling parts

It should be noted that the participants were instructed not to make drawings during the design activity. While it is well known that sketching is a key activity in design, the goal of the experiment was to assess the relationship between design-and-building activity and a participant's engagement in the activity. If sketching had been permitted, the results could be potentially confounded.

Design outcome measures

Three measures of design outcome were observed:

1. Maximum vertical displacement of ball: the vertical displacement was determined by the initial and final position of the ball. A one-time measurement was made for each design at the end of the time limit.
2. Novelty of designs. The novelty of the designs was assessed based on methods introduced by Shah *et* al. [42]. Each design was divided into four attributes: ball-raising mechanism, ball attachment method, footprint of structure, and structural rigidity. Each attribute was given a novelty score S_i and a weight p_i, so the overall novelty of ideas within each group can be computed by:

   $$\mathbf{M_{Novelty} = \sum_{i=1}^{4} S_i p_i} \qquad \textbf{Eq. 1}$$

   In the following result analysis, the weight p_i (i=1, 2, 3, 4) was chosen to be 1, therefore all four evaluation criteria for novelty are of equal importance.

   For each design, the solution of every attribute was categorized. The novelty score, S_i, was given by:

   $$\mathbf{S_i = \frac{T_i - C_i}{T_i} \times 10} \qquad \textbf{Eq. 2}$$

   Where $\mathbf{T_i}$ is the total number of solutions produced for the ith attribute and $\mathbf{C_i}$ is the count of the current solution for that the i^{th} attribute. Multiplying by 10 normalizes the expression**.**

3. Participant's own assessment of their experiences during the design-and-build activity. A post-completion survey asked participants to note how frustrated or calm they felt during building, how satisfied they were with their final design, and how confident they were during the process of designing, all using 7-point Likert scale (as described by Witmer et al).
4. The quantity of concepts generated, as reported by the participant.

Results & Discussion

All statistical analysis is given in the following format: mean ± standard deviation. All 30 participants completed a mechanism within the allotted 30 minutes. The average displacement measured was

21.43 ± 15.46 in. The minimum displacement was 0 in (non-functional design) and the maximum displacement was 64 in.

Efforts have been made to find correlations between the design outcome, presence and immersion levels, demographic data, and post-survey results. MANOVA was used to determine interaction effects between the factors (e.g. the interaction effects of demographic information and presence level on the design outcome). However, no significant correlation emerged between these factors. Additionally, one-factor regression model and ANOVA have applied, which revealed some significant results. These, together with other important analysis, are presented in the following.

Presence

The mean PQ score for the 30 participants was 106.32±18.05, with a maximum score of 133 and a minimum of 66 (see Figure 3). As a reference point, a score of 100 means that an individual has a high sense of presence. Displacement was plotted against presence, and fitted with a quadratic model:

$$\text{Displacement} = -47.143 + 0.582\ \text{Presence} + 0.019\ (\text{Presence}-106.333)^2 \qquad \textbf{Eq. 3}$$

Where Displacement is the maximum ball displacement, Presence is the score on the PQ. ANOVA was used to analyze the data. The result showed significance of the model with $F(1,28)=7.2236$, $p = 0.0031$.

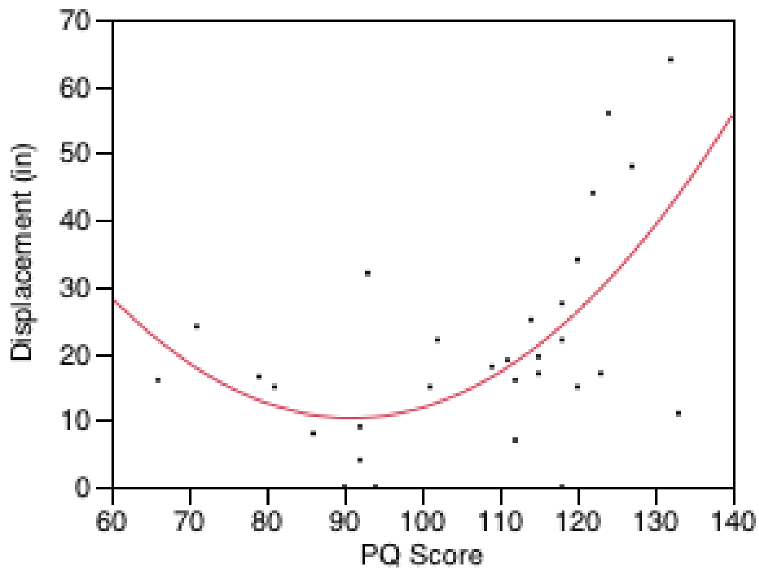

Figure 3 Ball displacement vs. PQ score, curved trend line shown

The quadratic model shows that, participants who were the least present did not necessarily perform the worst. However participants with highest presence scores did tend to attain a higher ball displacement. This could mean that people who are deeply engaged "in the moment" produce more effective designs. This finding is consistent with our initial expectation of the link between presence and design outcome.

Immersive Tendencies

The mean score for the 30 participants on the ITQ was 107.27±16.60, with a maximum score of 147 and a minimum of 73. A higher score on the ITQ means a higher level of immersion. An ANOVA analysis did not show a statistically significant correlation between immersive tendencies and design outcome with $F(1,28)=0.499$, $p=0.486$ (Figure 4).

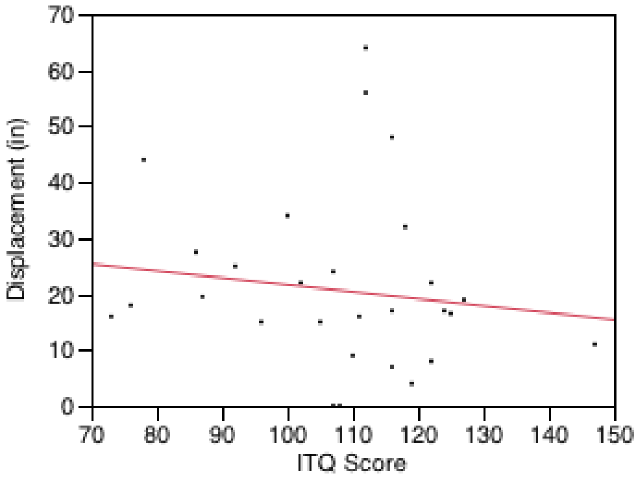

Figure 4 Ball displacement vs. ITQ score, linear trend line shown

Immersion vs. Presence

Because immersive tendency can lead to presence, the correlation between immersion and presence is examined. One might hypothesize that a participant with a higher immersive tendency would also score higher on presence.

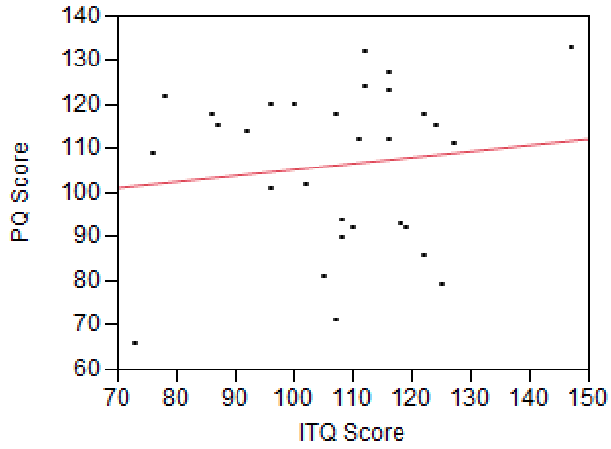

Figure 5 PQ score vs. ITQ score, linear trend line shown

Immersion plotted against presence is shown in Figure 5. An ANOVA was determined for the correlation of immersion and presence, showing no significance of the model, F(1,28)=4.623, p=0.502.

Types of designs and immersion

All the devices generated by the participants were analyzed by the authors after the fact to determine if there were common types of designs. Surprisingly, three distinct categories of devices emerged. First, mechanisms were identified as pulleys if the mechanism used string to enable ball displacement. Second, mechanisms that relied on a pivot point were categorized as fulcrums. Lastly, a mechanism was typed as a catapult if the ball required exiting the mechanism at any point. Ball attachment to the mechanism could also be placed into two categories. One was a loose connection (ball was placed in some type of basket or other holding mechanism), but there was no physical connection between the ball and the support structure. The second connection was made either with string or with rubber bands or a combination of rubber bands, string and metal pieces, typically seen in fulcrums and pulley designs.

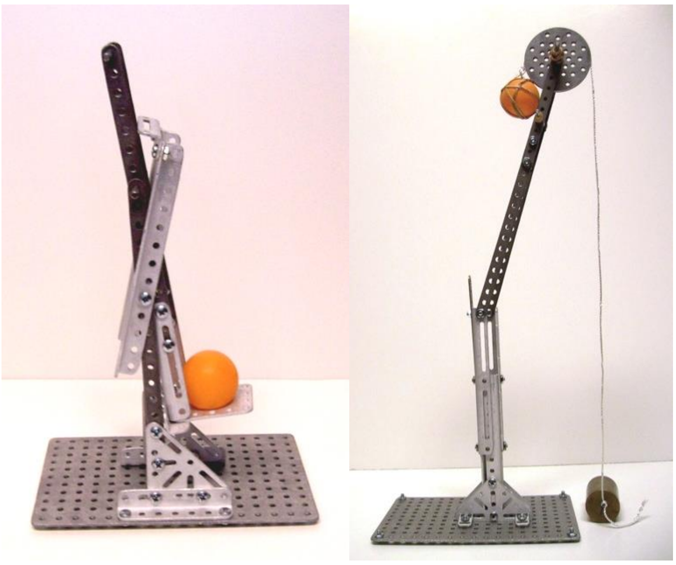

Figure 6 Example of a fulcrum design (left) and pulley system (right)

Figure 7 shows a box plot distribution of each of the mechanism displacement. Thirteen participants designed a pulley system (18.19 ± 4.46 in), ten participants created a catapult (21.85 ± 5.08 in), and seven implemented a fulcrum (23.79 ± 6.07 in). A one-way Analysis of Variance (ANOVA) was used to test the difference in performance among the three types of structures and the differences were not found to be significant, $F(2, 27) = 0.3129$, $p = 0.734$.

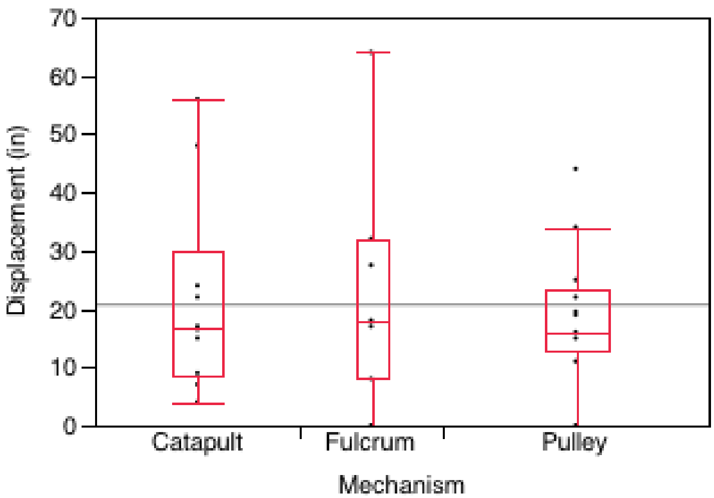

Figure 7 Box plot of the ball displacement differences between different types of design (fulcrum, catapult, pulley)

Tukey post-hoc comparisons of the catapult (M=114.8, p=0.069), fulcrum (M=114.8, p=0.302), and pulley (M=114.8, p=0.557) indicate that building a certain structure did not result in a higher level of immersion (Figure 8). Participants who built a catapult had a higher level of immersion than participants that built a pulley, but the difference was not statistically significant.

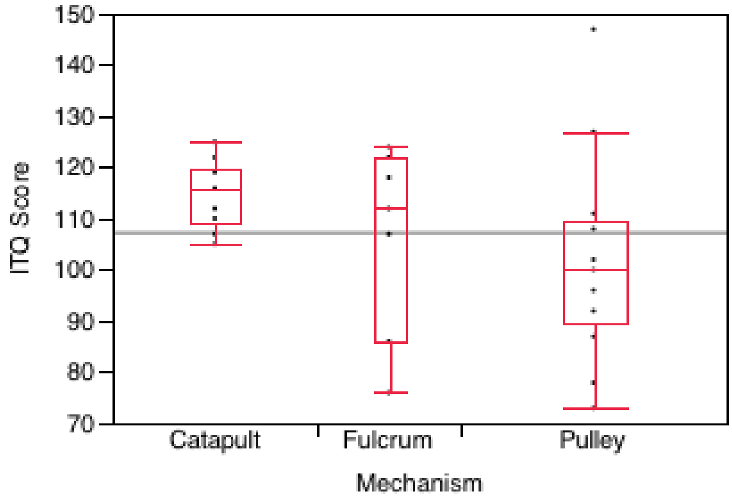

Figure 8 Box plot of ITQ score differences between different types of design (fulcrum, catapult, pulley)

Novelty of designs

The average novelty score was 25.2±2.3, with the highest score 32.03 and the lowest 16.66 (see Figure 9).

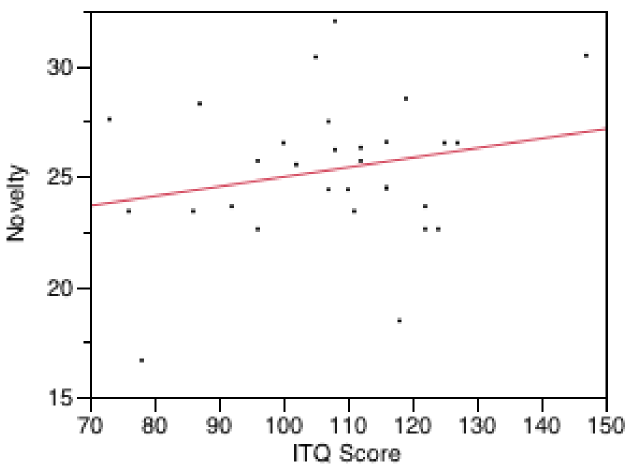

Figure 9 Novelty score vs. ITQ Score, linear trend line shown

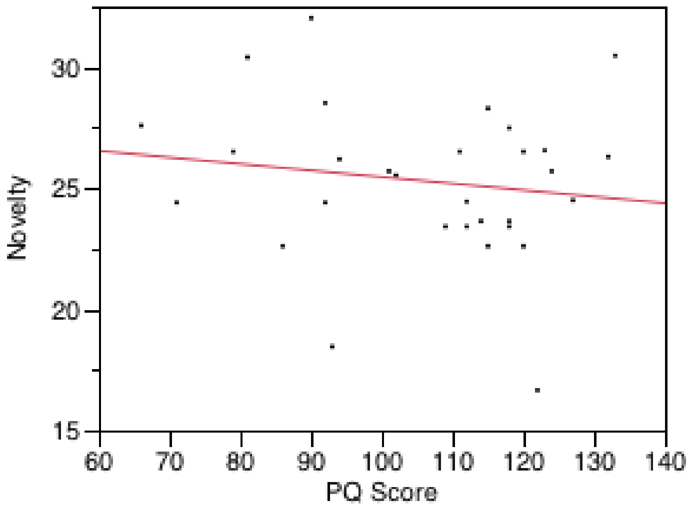

Figure 10 Novelty score vs. PQ Score, linear trend line shown

Figure 9 and Figure 10 show the novelty score versus immersion score and presence score respectively. No significant correlations were found, with ANOVA analysis results of $F(1,28)=1.4945$,$p=0.2317$, and $F(1,28)=0.6671$, $p=0.4210$, respectively. Figure 11 shows the novelty score plotted against the displacement of the raised ball. A second order fit can be found between the two data sets with a significant ANOVA analysis results: $F(1,28)=4.5603$, $p=0.0197$.

$$\text{Novelty} = 27.225 - 0.135\ \text{Displacement} + 0.004\ (\text{Displacement} - 20.717)^2 \qquad \textbf{Eq. 4}$$

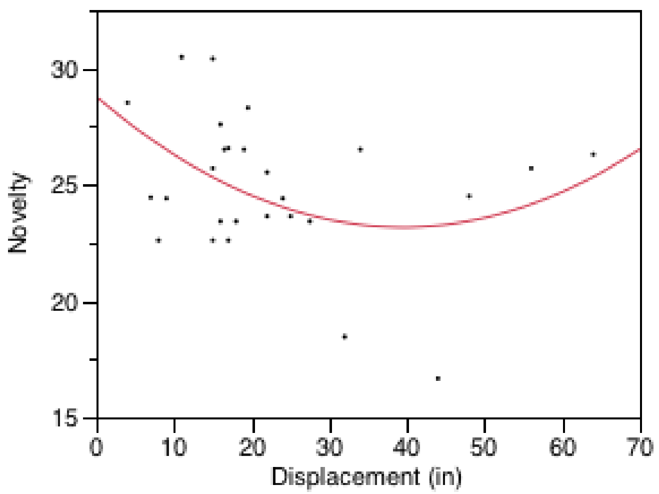

Figure 11 Novelty score vs. ball displacement, curved trend line shown

From the plot we can see that designs judged to have the highest novelty frequently did not work well (failed to raise the ball to high positions). However, those that did work well (raised the ball to a high positions) generally had rather high novelty scores.

Surveyed Qualities

The participants evaluated their frustration at 4.5 (interquartile range, 3.25-6), indicating a low level of frustration. They reported that they were highly engaged during the activity at 5.87 (interquartile range, 5-7). Furthermore, the participants were satisfied with their final designs (4.2, interquartile range 3-5) and would continue on their designs if they had been given more time (6.7, interquartile range 7-7).

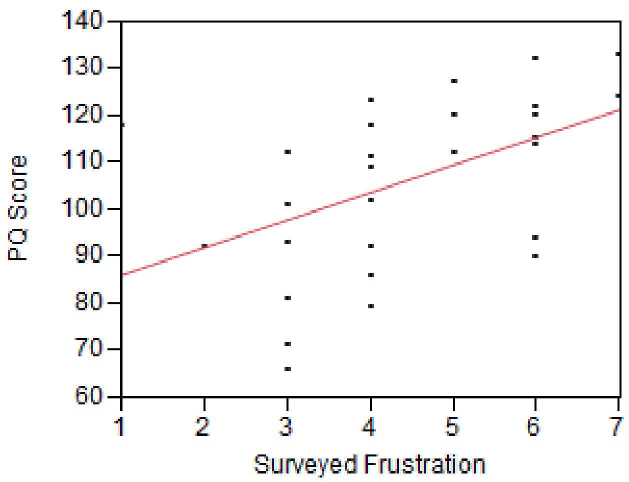

Figure 12 PQ Score vs. Surveyed frustration, where 1 was frustrated and 7 was calm, linear trend line shown

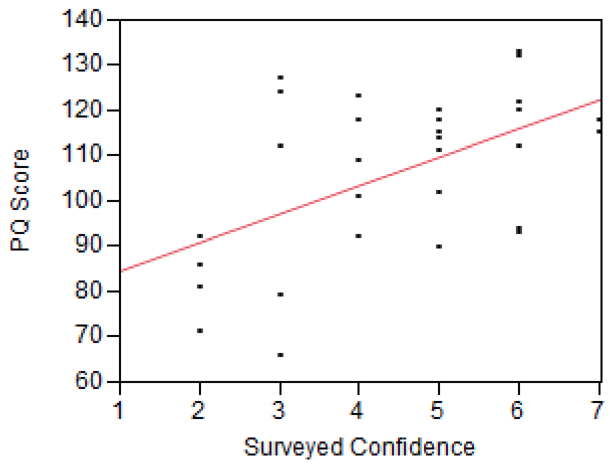

Figure 13 PQ Score vs. Surveyed confidence, where 1 was unconfident and 7 was very confident, linear trend line shown

Figure 12 shows the surveyed frustration levels and the presence score. An ANOVA result shows significance of the fit with F(1,28)=8.7239, p=0.0063. Figure 13 shows the surveyed confidence levels and the presence score. An ANOVA result shows significance of the fit with F(1,28)=11.0221, p= 0.0025. Participants who reported feeling calm and confident during the design activity also experienced a higher level of presence.

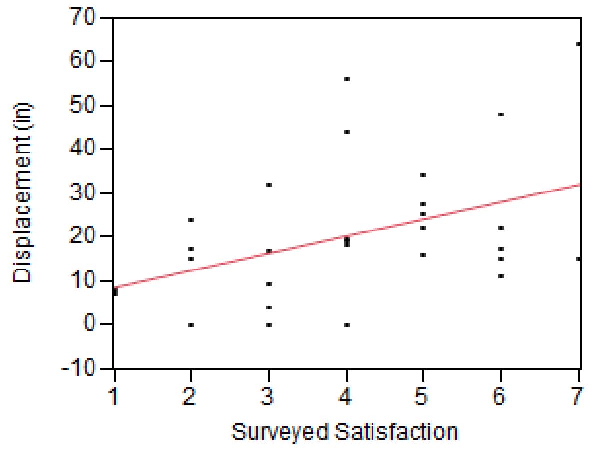

Figure 14 Displacement vs. Surveyed satisfaction, where 1 was unsatisfied and 7 was satisfied, linear trend line shown

Figure 14 shows the surveyed satisfaction levels and the Ping-Pong ball displacement. An ANOVA result of F(1,28)=6.0069, p=0.0208 indicates a significant correlation where participants that built a better functioned Ping-Pong ball displacing device felt more satisfied with their designs. Note that this feeling of satisfaction was independent of any outside knowledge of how other participants' devices performed.

No correlation between immersion and level of frustration or lever of confidence was found. Additionally, no correlation between the type of design and surveyed qualities (frustration, engagement) were found.

Quantity of concepts

In addition to the surveyed qualities, the participants were asked how many concepts they generated before settling on their final design. Participants reported exploring an average of 2.9±1.7 ideas during the design period (interquartile range 2.3-3.5). Only 1 participant explored more than 10 ideas. A bivariate linear fit with a resulting $F(1,28)=0.665$, $p=0.422$ (ANOVA) showed no correlation between immersive tendencies and number of ideas generated. There correlation between presence and number of ideas resulted in $F(1,28)=1.049$, $p=0.314$ (ANOVA), showing that participants who explored a higher number of concepts had a tendency for higher levels of presence.

Gender

Performance of the design activity between genders was analyzed using a one-way ANOVA. The design outcome for male participants was 22.61±4.23 in and for female participants 19.06±3.74 in ($F(1,28)=0.373$, $p=0.546$). Female participants scored 108.29±4.50 the ITQ while males scored 106.38±4.22 ($F(1,28)=0.096$ $p=0.759$). In the PQ, Male participants scored 103.25±4.51 and female participants scored 109.86±4.82 ($F(1,28)=1.000$ $p=0.336$). Figure 15 shows the displacement outcome of the design for each gender.

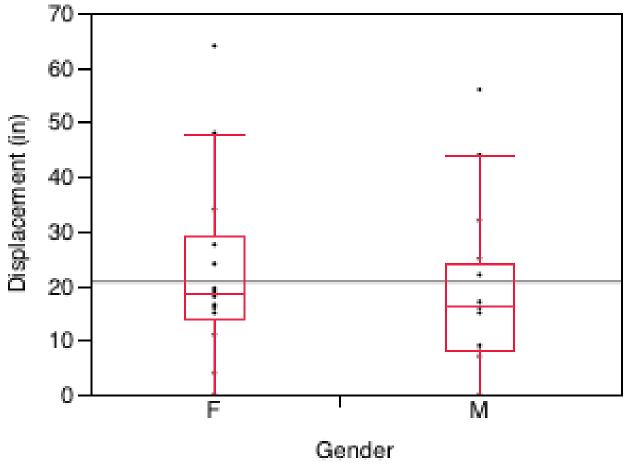

Figure 15 Box plot of ball displacement differences between female (F) and male (M) participants

Statistically speaking, there are no significant differences between the design outcome, immersive tendency and presence score and gender.

Education Level

Performance of the design activity between participants with different education level was analyzed using a one-way ANOVA. The design outcome for high school degree participants was 21.44±22.05 in, for bachelor degree participants was 21.25±12.14 in, and for master degree participants was 18.71±14.69 in ($F=0.0700$, $p=0.9325$).

High school degree participants scored 114.67±15.15 in the ITQ, while bachelor degree participants scored 107.00±16.11, and master degree participants scored 98.29±116.94 ($F=2.0615$, $p=0.1468$). In the PQ, high school degree participants scored 110.67±20.93, bachelor degree participants scored 109.28±13.31, and master or above degree participants scored 94.86±20.12 ($F=1.9883$ $p=0.1565$).

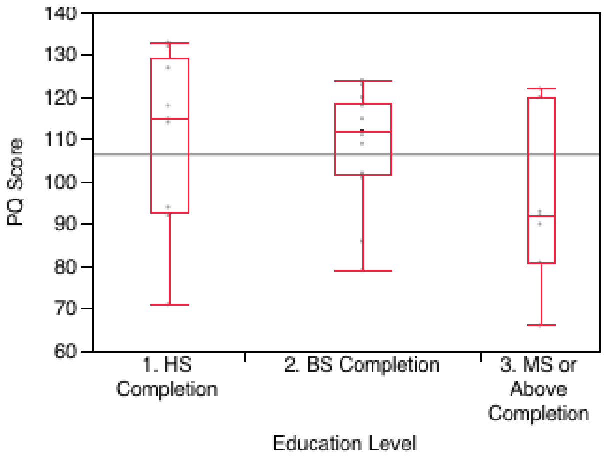

Figure 16 Box plot of PQ score differences between different education levels (H.S. = completed high school, BS = completed Bachelor of Science, M.S. = completed Master level or above)

It is interesting to see that, participants with the highest education level (Master degree) have the lowest average immersion and presence score, and their average design outcome is the lowest too. Conversely, participants with the lowest education level (high school degree) have the highest average immersion and presence score as well as the best averaging design outcome. However we cannot draw any conclusions about whether education level makes a difference or not since the differences are not significant.

Observations

All participants completed building a mechanism within 30 minutes. Only one participant built a design that was non-functional. In general, simple mechanisms (fewer parts) performed better than ones with more parts and complexity. This finding is consistent with earlier work [14]. Though given the chance to test the design during the building phase, none of the participants did so. The only testing of the mechanism was during the actual evaluation period at the end of 30 minutes. This is likely because the 30-minute time period was roughly the minimum amount of time needed to finish the design task. Most of the participants concentrated on building their design up until the last minute. Most participants began building immediately and did not spend time “playing” around with the building blocks. Most focused on assembling a single complete design in the time allotted, as had been intended by the experimenters.

Often, the generation of few ideas typically suggest design fixation (reduced range of solutions, low novelty) has occurred [43]. Design fixation is a real problem in design practice and in the classroom, particularly when aspects of an example solution appear in the generated solutions. However, in this study, no example solutions were shown prior to the start of the design activity, and the 30 minute time constraint of the experiment was intended to allow the building of one solution, rather than several. It is unclear whether fixation was occurring during the experiment. All participants' design fell into 3 distinct categories, all of which were common mechanisms that the participants would likely be familiar with. However, the goal of the task was not to produce a novel design, but to produce a design that would raise a ball as high as possible.

If more time had been available for the experiment, we conjecture that participants would have explored more designs. In addition, despite instructions during the design briefing that no sketching is allowed at any time, a third of the participants asked if they could sketch. While sketching certainly aids in rapid generation of ideas, idea generation was not the focus of this user study.

Conclusions

1. *What is the nature of immersion and presence in the context of early stage design-and-build activities?*

Results indicate that designers' sense of immersion and presence ranged widely, as well as their sense of frustration and calmness while performing the design activity. Participants with higher presence scores tended to attain ball displacements at both ends of the spectrum, very high and very low. This study did not show effectively that people, who were more engaged "in the moment" might be able to produce more effective designs or noticeably poorer designs. This finding is somewhat consistent with our initial expectation of the link between presence and design outcome. This experiment did not reveal any significant correlation between immersion and presence. Previous research efforts [22, 44, 45] suggest that higher levels of immersion lead to an enhanced level of presence. This experiment did not confirm those studies, perhaps because of the physical nature of the prototyping environment made available to the subjects, rather than a virtual prototyping environment.

This experiment suggests that immersive tendencies are not linked to design outcome for this type of design-and-build task. Our observations of the participants showed that they generally spent all 30 minutes steadily building a single design. It’s not clear why they did not explore more designs in the 30 minutes.

2. Do immersive tendencies correlate with better design?

Significant correlations between presence and ball displacement were found, but not between immersion and ball displacement. One possible reason is that this study assumed that if someone is not engaged or absorbed in an activity, they cannot do well. What this study suggests is the engagement/absorption is a necessary but not sufficient condition for performance. Just because an individual feels engaged in activity in the present moment doesn't mean he is excited about it or has a sense of playfulness as one might while immersed in an activity.

Most participants felt that if they had a goal to beat, their priorities would have changed. Instead of making a nice looking design (i.e. keep ball horizontal), they would have designed a less “elegant” design if the activity would have been more goal oriented. Few asked about using table as advantage and gain extra ball displacement. Only 3 asked to use of table to “extend” displacement to floor because there was no rule on table use.

Novelty seemed to be important creating a successful design, but ideas that were the most novel (at the extreme end) were not as successful as those that were slightly less novel. Designs of average novelty generally functioned well. These were lower risk ideas with a lower chance of failure, but were also less likely to be the most successful.

The implications of these findings are of interest for both education and practice. The underlying model behind active learning [46] is that learners will gain greater understanding if they are deeply engaged through learning activities beyond simply listening. Hands-on, design-and-build tasks are inherently an “active” design experience for the participant, but the results of this work suggest that the level of engagement is relevant, and that engagement (presence) could serve an indicator of design performance and learning.

Future Work

Design is a complex activity with many potential factors that can influence its outcome. In this study, the role of immersive and presence tendency in the design process were considered. This study focused on a design-and-build activity so as not to confound the results, but future work could consider other activities that typically occur in concert with design-and-build. These include the act of sketching of potential design concepts during initial idea generation, as well as later in the design process. Sketching activity may provide a tool with which to observe design thinking and provide more insight into immersive tendencies. Sketching is a key activity in design and many designers start with a sketch before they iterate on their designs. Because the goal of the experiment was to assess the relationship between design-and-building activity and a participant's engagement in the activity, sketching intentionally was not allowed. There is certainly the possibility that the results would be different if sketching had been permitted. In addition, future studies could examine how the physical act of fabrication of parts can affect the sense of engagement. The larger goal of this work would be to formulate a richer, more comprehensive understanding of immersive tendencies of designers while engaged in early stage design activities.

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