Research on the performance evaluation and preference of design thinking methods in interdisciplinary online course

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Under the COVID-19 epidemic, faced with the problem of ensuring the quality of teaching online, Design Thinking, as a design teaching and evaluation tool for interdisciplinary collaborative courses, has attracted much attention. This research purpose is to explore the learning performance and using preference of four popular design thinking methods in interdisciplinary online courses. This study took an intensive online course for graduate students jointly held by two departments, information engineering and industrial design, as the case study. It developed curriculum based on Brainstorming, Crazy 8, User Journey Mapping and Storyboarding. Quantitative evaluation and Evaluation Grid Method were adopted to compare participants’ performance and preference of these four design thinking methods. The results revealed that, compared with Crazy 8, Brainstorming which has the characteristics of open communication and out-of-convention ideas may be the reason why industrial design students are more prominent in Flexibility and Elaboration. By contrast, compared with User Journey Mapping, Storyboarding performed better in Originality and Elaboration than others. This study provides an educational scientific reference of design thinking methods and expects to help educators improve the design curriculum in the future.

Keywords: Interdisciplinary education, Cooperative design, Learning performance assessment, Information engineering, Industrial design

Introduction

The outbreak of the novel coronavirus pneumonia (COVID-19) in 2019 had a huge impact on higher education, forcing traditional offline teaching modes to become unsustainable. Colleges and universities should initiate appropriate measures and enter into the large collaborative online teaching practice in history as quickly as possible, which arise difficulties and challenges for higher education. Since there is as yet no unique online teaching mode for all subjects (Palloff & Pratt, 2013), most teachers face a challenge of their technical and administrative skills in online teaching (Albrahim, 2020). Outcome-Based Education (OBE) emphasizes that the focus of instructional design and implementation goals are on students' internalization and practical application of learning, and that assessment criteria are revised at the right time to accurately capture students' learning status (Bhat, D'Souza, Bhat, Raju & Kumara, 2020). Based on OBE, the main difficulties for higher educators when implementing online collaborative courses arise from the complexity of the learning environment, the difficulty of planning and organizing courses, and the difficulty of assessing teaching and learning, including the selection of online platforms, teaching tools and the planning of their operational processes (Rapanta, Botturi, Goodyear, Guàrdia & Koole, 2020); the establishment of forms of teacher-student interaction (Bervell, Umar & Kamilin, 2020); the organization of online design courses across domains (Iwasa, Hayashi & Ohsawa, 2020); The development of appropriate learning performance evaluation criteria for all the students with different masteries of learning content, access, and breadth and depth of online courses (Hsu & Ching, 2013). Therefore, the corresponding need for an effective and innovative teaching mode to ensure the learning performance of online collaborative teaching is proposed at this stage. Design thinking is a human-centered problem-solving approach for collaborators on interdisciplinary
collaboration, team coordination, and solving problems. It supports interdisciplinary members to generate more feasible and sustainable solutions (Arias, Eden, Fischer, Gorman & Scharff, 2000). The double diamond design model, proposed by Design Council in 2004, is considered to be one of the most effective and convincing design thinking process models (Design Council, 2019). This model systematically divides the design process into two diamond (divergence and convergence) stages. In the first divergence stage, the user’s needs and contact points can be extensively collected. In the first convergence stage, designers can focus on the key contact points of design requirements and the relationship among each contact point in the process. The second divergence stage is based on the convergence results of the previous stage to develop the design concepts. The second convergence stage is that designers use feedbacks from users and experts to make decisions on the design concepts to obtain the final solution (Przybilla, Klinker, Wiesche & Krčmar, 2018).

Currently, in the design course, the commonly used design methods in the divergence phase, including Brainstorming, Empathy Map, Crazy 8, 5W1H and AEIOU etc. The methods in the convergence phase which design courses used mostly, including Point of view (POV), How might we, Persona, User journey mapping and Story Boarding etc. The first divergence and convergence stage is the key to establishing the foundation of a successful concept. Therefore, more attention is paid to train the abilities of the first stage in the design courses. In addition, research on the above-mentioned commonly used design methods are increasing. Among them, we found four methods, Brainstorming, Crazy8, User journey mapping, Storyboarding, are more widely used in the first stage. A number of studies have pointed out that Brainstorming is the most prominent way of producing ideas (Cross, 2000; Paulus & Nijstad, 2003), while startups in Silicon Valley emphasize Crazy8’s acuity and efficiency in generating ideas (Levey, 2016). On the other hand, User Journey Mapping can effectively help design students teams to collaborate and reflect on the design process (Sperano, Roberge, Bénech, Trgalova & Andrichow, 2018), while Storyboarding has a better, more understandable and enjoyable experience for novice designers (Truong, Hayes & Abowd, 2006). The professional courses of many fields in higher education involving the conceptual development of prototype design states that prototype activity is a necessary process for the curriculum. Based on the advantages of creativity & innovation, user-centered aspect, participation and problem-solving, more and more higher educators try to apply Design thinking methods to the concept of prototype design in related courses (Abedianpour & Omidvari, 2018; Michelli, Wilner, Bhatti, Mura & Beverland, 2019). Shinohara, Bennett, Wobbrock & Pratt (2017) apply user-centered design methods with design thinking concepts including needs assessment, user interviews, brainstorming, ideating, synthesizing, low-fidelity prototyping, high fidelity prototyping and usability testing in a technology design courses aimed at the students of computer science and information technology. The observed results of the subjects show that students can produce a large number of ideas by conducting Brainstorming before prototyping. Besides, brainstorming also help students master the learning tasks of the course. A design course about the Internet of Trusted Things (IOTT), which researches on the learning quality and relevant experience of Computer Science and Design & Art students, shows that Crazy 8 is an easy and quick method for students from different professions to use. Especially, Crazy8 is useful to converge ideas and determine whether the idea is feasible or not in the design conception stage. The overall qualitative evaluation and student satisfaction of the product prototype are both positive (Gennari & Melonio, 2019). The results of a case study of an undergraduate computer course point out that it is important to apply Crazy 8 which can help students produce better design solutions in the innovation and problem-solving process at the prototype stage (Ferreira & Canedo, 2019). An intervention design course for master students in interaction design, which researches on teaching instructional design tools, states that the use of User Journey Mapping is meaningful for students to realize the sharing of knowledge and practice, collaboration and reflection, and can provide a richer view of the design process in the discipline of instructional design (Sperano, Roberge, Bénech, Trgalova & Andrichow, 2018). A case study of design courses in the fields of software engineering and human–computer interaction proposes that design thinking methods and interactive scenarios, which students use the software system to communicate with all stakeholders and Storyboarding to present their concepts, can help produce more resonant interactive design concepts effectively (Péraire, 2019). A study of higher education courses by Lu & Hsiao (2019) believes that the Evaluation Grid Method (EGM) has advantages of deeply uncovering the attractive factors of the products required by users. In a course, EGM can objectively and effectively help educators capture students’ preference of using design tools.

Most studies describe the effectiveness of the above design thinking methods, but there are few studies describing the learning effectiveness and students’ preference aiming at research courses. Therefore, in order to better understand the applicability of these four design thinking methods in the current complex interdisciplinary collaborative online courses, this study takes a graduate interdisciplinary online course as a case study to compare Brainstorming with Crazy 8 and User Journey Mapping with Storyboarding, which are applied to verify the learning effectiveness of the students in the course, and conduct the EGM to explore the
students’ preference factors of design thinking methods. It is expected that this study helps higher educators improve curriculum design and evaluation of learning outcomes.

Theoretical background

Design thinking Methods
Design thinking, proposed by IDEO, emphasize human-centric innovative method of problem-solving, which take human needs and behaviors into account, as well as technological and commercial viability which is emphasized in the past. It has a unified problem-solving strategy and can help designers solve complex design problems (Brown & Katz, 2011; Liedtka, 2015).

Brainstorming, proposed by Alex Osborn in 1938, is a method to stimulate creativity and strengthen thinking. It is one of the main methods in interdisciplinary creative teams (Osborn, 1957; Dennis & Williams, 2003; Ivanov & Zelchenko, 2019). The basic rules are to pursue quantity of ideas, to prohibit criticism, to promote unique and creative ideas, and to synthesize and improve ideas. It can be done by one person or a group of people, and the participants will sort out all the ideas that follow the basic principles. During the whole process, the opinions and insights from everyone must not be criticized. It’s better to generate as more ideas and problem-solving methods as possible.

Crazy 8 is a kind of design sprint method, proposed by Google Ventures, requiring each person to come up with 8 solutions to a problem in 8 minutes. It is a challenging but quick way to draw rough sketch which is popular among design companies. It does not require a complete solution, so as to avoid influencing each other’s ideas and to promote independent thinking. When Crazy 8 being implemented, the ideas are presented in simple drawings or written solutions (Jones, Nabil, & Girouard, 2021; Knapp, Zeratsky, & Kowitz, 2016).

User Journey Mapping was first introduced in service design by IDEO. Subsequently, it became one of the most widely used design thinking methods. It can help design teams to better understand each stage of the customer’s use of the service process, including the touch points of the entire process before using, during using and after using in a process. It also visualize the experience of stakeholders interacting with a product or service to enhance design impact and elevate it to a strategic level (Brown & Katz, 2011). Following are the five steps:

1. Use the stakeholder map to identify core stakeholders and other stakeholders
2. After a discussion, divide the experience into different stages
3. The touch points corresponding to each stage, includes stakeholders, environment, systems, and items
4. Collect the behaviors, thoughts and feelings of stakeholders according to the description of the touch points at each stage
5. Combine the above-mentioned information to describe the relationship between interest and emotional ups and downs at each stage

Storyboarding was first used in the field of developing movies, Television clips and animations, and was later introduced into the development stage of the design field (Hart, 2013; Truong, Hayes, & Abowd, 2006). It is a method of visualizing story content that allows design teams to predict the problems, motivations and experience that users may encounter in the expected situation. The final presentation can provide visual demonstration for users, allowing the design teams to build the contact points of multiple modal based on empathy for users in the convergence stage, and achieve a rich description of the contextual environment (Rasool, Molk-Danielsen, & Smith, 2020; Shi, Cao, Ma, Chen & Liu, 2020). Following are the five steps:

1. Set characters, scenes and plots, which the story content can describe the interaction between the product and the expected users. Next, connect the entire story script in the way of people, events, time, place, and things. Final, set the overall story with characters and scenes and the possible plot.
2. Draw a simple plot according to the set story environment, try to avoid unnecessary plots through easy-to-understand sketches and tell others the story you want to tell clearly.
3. Add your script to add emotion to the plot. In the storyboard, the character should be the center, so it needs to reflect the character’s current thoughts and emotions. The plot which is given emotion makes readers get emotional resonance.
4. Draw the basic line draft of the overall story, transform each step into a picture, and show what happens at each moment and the current thoughts of the characters in the picture.
5. Design clear outcome. When the composition of the storyboard is completed, the steps of the
story will be obtained to discover the problems that users will encounter, so that we can better understand our users which the design team can share this knowledge. You can make more subtle adjustments to the content to make the plot flow more in line with the user’s thoughts.

Evaluation Method
The Evaluation Grid Method (EGM) was proposed by Sanui, which was improved based on the Repertory Grid Method (RGM), proposed by Kelly (Kelly, 1955; Sanui, 1996). EGM gains insights from the cognitive aspects of subjects’ perception of a specific thing in depth. It can accurately extract attractive factors from the thing based on individual thought. In the implementation, participants compare the target objects A with B through personal interviews. Next, participants clearly discuss the similarities or differences between them, and acquire three levels of evaluation items of their strengths or weaknesses, i.e., the abstract concepts which are defined as upper level, original evaluation item characteristics (factor) which is middle level and the specific constituent elements or conditions which is lower level. Finally, draw the evaluation structure chart, so as to vague and implicit user emotional preferences to quantify and filter out the key charming factors.

Research Process
The process of this study is divided into two phases. In the first phase, after confirming the online platform, Brainstorming and Crazy 8 were applied to generate and develop the ideas of users’ needs; User Journey Mapping and Storyboarding were used to develop the concepts on user experience. The second phase was the evaluation phase, in which the experts conducted an assessment of the learning performance of the four design thinking methods, and the interviewees used the EGM to conduct two comparisons of the two groups of methods which uncovered users’ needs and developed concepts on user experience. In consequence, the combined analyses of results were examined to understand the applicability of the design thinking methods and the students’ preference for the application of the methods in the course.

Case study and Results
Experiment Phase
The case study was an online course for graduate students which jointly organized by National Cheng Kung University (Taiwan) and the Nara Institute of Science and Technology (Japan), with a two-day intensive course on Sustainable Development Goals (SDGs) in December 2020. This course included 3 times in six weeks and the interval between classes was two weeks. Each instruction class was 5 hours and the rest time of a day was the discussion time for each group. The spoken language of course was English. A total of 40 participants, including 7 doctoral students and 33 master students, were divided into 10 groups including 4 students in each group. All of students are from two disciplines, information engineering and industrial design. The course chose two online platforms, Remo and Miro, for online teaching and team discussion. Remo is used for the instructor to assign tasks and observe and communicate with groups, and Miro is used for students to practice design thinking methods and demonstrate their learning performance.

In the first class, participants prepared for the group icebreaking activity based on the course theme and the instructors introduced how to operate four Design thinking methods. In view of expecting all the course participants benefiting from learning four design thinking Method as the course goal, the results and analysis of this research did not form a control group (all process of the tasks is not guided by the instructors).

In the second class, based on the SDGs, participants carried out an exploration of producing ideas of users’ needs, Brainstorming and Crazy 8 methodologies were implemented with different tasks. The task of the former was to develop and converge the design requirements for users based on the topic. Each group of students developed positive and negative design requirements (15 minutes) and then shared and discussed with all the course participants to select the best design requirements (30 minutes); the task of the latter was to develop and converge the specific product requirements for the proposed design direction. Each group of students conducted two rounds of crazy 8 questions (8 minutes each), and then shared and discussed with all the course participants to filter out the best product requirements (30 minutes). The rest of the course time was spent on the preparation and production of the team’s outputs.

In the third class, participants devoted themselves to developing concepts of user experience based on the same topic. There were different implementation tasks in User Journey Mapping and Storyboarding. The task of the former was based on empathy to diverge and converge the touch points of the product using process. Each group of students conceived the touch points (30 minutes) and then shared and discussed with all the course participants to identify the touch points of the product using process (30 minutes); the latter task was
to conceptualize and visualize the touchpoints of user-product interaction circumstances. Each group visualized the interaction circumstances (30 minutes) and then shared and discussed with all the course participants to identify the touchpoints in the product interaction context (30 minutes). Each group's outcome was presented based on the standard criteria of the four design thinking methods. The rest of the course time was spent on the preparation and production of the team's outcomes.

Figure 1. The outcome of Brainstorming and Crazy 8
Take one of the groups in this course as an example. This group addressed the problem of high neonatal mortality around the Least Developing Countries (LDCs). So, they sought the solutions to provide immediate healthcare for newborn babies in LDCs. Figure 1 shows the outcomes of their design diverging ideas and converging design goals based on Brainstorming and the outcomes of design concepts and two converging directions for continued development by using Crazy 8. Figure 2 shows the outcomes of User Journey Mapping and storyboarding which are applied to find out more accurate user experience and to develop the user scenario.

The Assessment of Course Outcome

The Torrance Tests of Creative Thinking are based on four scales of creativity, Fluency, Flexibility, Originality and Elaboration. This study assessed all the group performances on a 5-point Likert scale. Fluency refers to the number of ideas, Flexibility refers to the diversity of ideas, Originality refers to the rarity of ideas, and Elaboration refers to the completeness and precision of the presentation of ideas. Since the course results of one group were not well-recorded, the results of nine groups were evaluated. Two teachers from Information Engineering and Industrial Design majors rated the performances of four design thinking methods (Brainstorming, Crazy 8, User Journey Mapping, and Storyboarding) of each group. After it, we used descriptive statistics and paired sample t-test to check the learning performance of the four design thinking methods which were divided into two kinds. The results are shown in Table 1 and Table 2.
Table 1. Descriptive Statistics related to learning performance

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>M</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>B 3.972</td>
<td>9  .599</td>
<td>.200</td>
<td>S 3.889</td>
<td>9  .636</td>
<td>.212</td>
</tr>
<tr>
<td>C</td>
<td>3.583</td>
<td>9  .515</td>
<td>.172</td>
<td>U 3.194</td>
<td>9  .702</td>
<td>.234</td>
</tr>
<tr>
<td>Fluency</td>
<td>B 4.333</td>
<td>9  .791</td>
<td>.264</td>
<td>S 3.944</td>
<td>9  .768</td>
<td>.256</td>
</tr>
<tr>
<td>Flexibility</td>
<td>B 3.833</td>
<td>9  .750</td>
<td>.250</td>
<td>S 3.667</td>
<td>9  .707</td>
<td>.236</td>
</tr>
<tr>
<td>C</td>
<td>3.611</td>
<td>9  .546</td>
<td>.182</td>
<td>S 3.167</td>
<td>9  .791</td>
<td>.264</td>
</tr>
</tbody>
</table>

B - Brainstorming, C - Crazy 8, S - Storyboarding, U - User Journey Mapping

Table 1 shows that, among the nine groups of students, Brainstorming is the highest overall learning performance of the four design thinking methods, and User Journey Mapping is the lowest. Among the four creativity scales, Storyboarding puts in the highest learning performance at Originality. Brainstorming puts in the learning performance at the other three creative scales. However, User Journey Mapping has the lowest learning performance in the four creativity scales.

Table 2. Paired t-test Statistics related to learning performance

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95%Confidence Interval for Mean</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>B - C</td>
<td>Total</td>
<td>.389</td>
<td>.211</td>
<td>.071</td>
<td>.226</td>
<td>5.518</td>
<td>8</td>
</tr>
<tr>
<td>Fluency</td>
<td>.222</td>
<td>.245</td>
<td>.073</td>
<td>1.017</td>
<td>.645</td>
<td>.537</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>.611</td>
<td>.690</td>
<td>.149</td>
<td>1.073</td>
<td>3.051</td>
<td>.016</td>
<td></td>
</tr>
<tr>
<td>Originality</td>
<td>.222</td>
<td>.222</td>
<td>.735</td>
<td>1.000</td>
<td>.347</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elaboration</td>
<td>.667</td>
<td>.250</td>
<td>.083</td>
<td>.859</td>
<td>8.000</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>S - U</td>
<td>Total</td>
<td>.694</td>
<td>.235</td>
<td>.078</td>
<td>.514</td>
<td>8.874</td>
<td>8</td>
</tr>
<tr>
<td>Fluency</td>
<td>.500</td>
<td>.500</td>
<td>.116</td>
<td>.884</td>
<td>3.000</td>
<td>.017</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>.500</td>
<td>.433</td>
<td>.167</td>
<td>.833</td>
<td>3.464</td>
<td>.009</td>
<td></td>
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<tr>
<td>Originality</td>
<td>.889</td>
<td>.347</td>
<td>.182</td>
<td>1.309</td>
<td>4.880</td>
<td>.001</td>
<td></td>
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<tr>
<td>Elaboration</td>
<td>.889</td>
<td>.333</td>
<td>.111</td>
<td>1.145</td>
<td>8.000</td>
<td>.000</td>
<td></td>
</tr>
</tbody>
</table>

B - Brainstorming, C - Crazy8, S - Storyboarding, U - User Journey Mapping

According to the results in Table 2, the critical value table of t-test shows that t=0.05(9-1)=1.860. In the comparison of the total scores of Brainstorming and Crazy 8 in the four creativity scales, the value of t=5.518>1.860, which means that the participants in nine groups had significantly higher learning outcomes in Brainstorming than Crazy 8. The value of t=3.051>1.860 for Flexibility and t=8.000>1.860 for Elaboration indicating that the performance for both of these measures of Brainstorming was better than Crazy 8.

In the comparison of the total scores of User Journey Mapping and Storyboarding in the four creativity scales, the value of t=8.874>1.860, showing that Storyboarding was more prominent than User Journey Mapping for student learning in this course. The t-values of both methods for the four creativity scales were significantly greater than the critical value, indicating that Storyboarding provides better performance than User Journey Mapping based on four creativity scales.

The Assessment of Using Preference

In the preliminary interviews of students’ preferences with participants, all students recognized that the course experience based on the four Design Thinking methods was satisfied and some students expressed their fondness for a certain design thinking method. In order to further understand students’ preferences in using all the four design thinking methods, 12 participants (6 students from industrial design and 6 students from information engineering majors) were recruited from the course participants who had clear preferences in the method and interviewed by adopting EGM. According to the results of the EGM interviews, among the four design thinking methods, 7 interviewees preferred Brainstorming (5 from industrial design and 2 from information engineering), 5 interviewees preferred Crazy 8 (1 from industrial design and 4 from information engineering). On the other hand, 12 interviewees preferred Storyboarding compared to User Journey Mapping. Therefore, we conducted EGM Interviews with the 3 most popular methods of interviewees. The evaluation structure chart is shown in Figure 3, Figure 4 and Figure 5.
Figure 3. Evaluation structure chart of Brainstorming

Figure 4. Evaluation structure chart of Crazy 8
Interviewees proposed different preference factors, and the number of times of each mentioned factor varied. During the Brainstorming interviews, ‘Sense of Leisure’ and ‘Pleasure’ were the most mentioned words by the interviewees, and the least mentioned word by the interviewees was ‘Sense of trust’. According to the Miryoku engineering perspective, ‘Sense of Leisure’ is the main factor affecting students' perceptual evaluation, while ‘Sense of trust’ is the least significant. In addition, according to the analysis of the construct elements corresponding to each perceptual evaluation factor, Brainstorming can be concluded that seven interviewees thought that ‘Mutually motivated discussion atmosphere’, ‘There are no comments on flaws’, ‘Unlimited free association of ideas’ which had the characteristics of ‘Open & free communication’ and ‘Break the conventional way of thinking’ brought them ‘Sense of Leisure’ and ‘Pleasure’. From the interview results of Crazy 8, it was found that ‘Concentration’ which was mentioned most frequently by the interviewees, was the main factor affecting participants' perceptions. While ‘Clarity’ which was mentioned the least (4 times) was the least significant. Five interviewees thought Crazy 8 was ‘Easy and efficient way to fill it out in the form’, ‘Concentrate on developing ideas’, ‘Need quick tempo to fill out all the blank’ which had the characteristics of ‘Clear and simple template & interface’ and ‘Short time limit makes efficiency’ could make them more ‘Concentrate’. From the interview results of the storyboarding, it was found that ‘Sense of Image’ and ‘Professionality’, which were mentioned most frequently, were the main factors affecting students' perceptual evaluation, while ‘Informative’, which was mentioned least, was the least obvious. Most interviewees believed that Storyboarding had ‘Humorous and exaggerated picture performance’, ‘Combination of pictures and text is easier to understand’. ‘Drawing gives the viewer imagination’ and ‘Images and texts deliver rich messages’, which can be corresponded to characteristics, ‘Lively and interesting way of expression’ and ‘Intuitive way of presentation’, so that bring them ‘Sense of Image’ and ‘Sense of Fun’ prominently.

Conclusion
Driven by the current global demand for online education, this study found ways to support higher educators to improve teaching curriculum implementation and ensure teaching quality in the complex education circumstances. This study examined the quantitative learning outcomes and qualitative using preferences of four design thinking methods through a graduate interdisciplinary online course. The results of this study show that the learning performance of the course is higher when using Brainstorming
and Storyboarding. The quantitative results show that students learn better with Brainstorming than Crazy8, which enables students to have more diverse and flexible ideas, and more detailed ideas. The results of the qualitative analysis show that, between the Brainstorming and Crazy 8, Brainstorming is more popular among industrial design students. They think that Brainstorming can help them to think and discuss without restrictions and openly. The main reason is that industrial design students have the personality of openness to experience, which have a significant correlation with the quantity of ideas and quality of the output (Bolin & Neuman, 2006). In addition, Urban & Jellen (1996) also believes that, in the design and creation, the personality of openness to experience and creativity are the most relevant among all the big five personality. Crazy 8 is more preferable for students majoring in information engineering. They believe that Crazy 8 has strict time pressure that can make people be concentrate, help improve efficiency, and make design ideas more focused. The main reason may be that students majoring in information engineering are better at systematic thinking which closely related to their professionalism. On the contrary, Design thinking methods that do not meet their professional characteristics will bring them more difficulty to learn (Dym, Agogino, Eris, Frey & Leifer, 2005). Integrated quantitative and qualitative analyses show that, compared with Crazy 8, industrial design students thought the characteristics of open communication and out-of-convention ideas can explain the reason why the Flexibility and Elaboration in the use of Brainstorming was more prominent. The quantitative results of User Journey Mapping and Storyboarding found that Storyboarding's overall learning outcomes and its learning outcomes on the four creativity scales (Fluency, Flexibility, Originality and Elaboration) are superior, they believed that Storyboarding increased the number of ideas and improved the creative quality of the ideas. The interview results revealed that Storyboarding was also favored by the majority of students, while User Journey Mapping was not significantly preferred by the students, mainly because the interesting and vivid presentation of Storyboarding was easier to convey the relevant messages they wanted to express. Integrated quantitative and qualitative analyses show that, compared with User Journey Mapping, all groups thought that Originality and Elaboration were more prominent than other two creativity scales in use of Storyboarding.

The research results show that it is feasible and effective to use design thinking methods in the course design and course assessment of Graduate Interdisciplinary Online Course. This study suggests that implementing Brainstorming and Storyboarding can improve students’ learning performance in similar courses. In design developing stage, Brainstorming is more suitable for students of industrial design, Crazy8 is more preferred by students of information engineering, and Storyboarding is more suitable for the students in these two majors. Because the study is based on the experimental results of a practical course, there might be limitations of the unstable online communication platform, small sample size in the implementation of the course, and the familiarity difference and understanding levels of four design methods between two departments. In the future work, it would be further explored on the learning performance of students' learning in similar courses using design thinking methods on different online communication platforms and increasing the sample size or setting more strict principles on sampling participants to obtain more valuable findings. The research results of this study can provide a kind of solution which using design thinking methods as the design teaching tools in graduate interdisciplinary online course.

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