Improving the Usability of Interactive Systems by Incorporating Design Thinking into the Engineering Process: Raising Computer Science Students' Awareness of Quality versus Quantity in Ideation

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***Abstract*—Traditional engineering methods are considered unsuitable for the development of usable and engaging interactive systems such as online experimentation and simulation software. For systems involving users, user-centric design approaches are more appropriate. The ideation stage of design involves exploring the space of opportunities. One commonly held view in design disciplines is that quantity leads to quality. Yet, for related non-design disciplines such as engineering, quantity is often regarded as a negative characteristic associated with low quality. Focusing on quality alone may lead to inferior user experience and ineffective systems. This study describes an initiative to (1) collect empirical evidence to support the design-belief that quantity leads to quality and (2) to use the activity and its results as part of a pedagogical strategy to enhance students' awareness of the connections between quantity and quality during ideation. A class of 100 computer science students was divided into two groups. Both groups were given the same task to design a text-input strategy for individuals with motor disabilities but with different focuses: one group was asked to focus on quality of ideas and the other group on the quantity of ideas. The results show that the students who focused on quantity of ideas produced better quality concepts compared to the students that focused on quality. The results were presented to and discussed with the students as a part of the learning process.**

Keywords—ideation, sketching, universal design education, human computer interaction, text entry, motor disability

I. Introduction

Systems targeted at end users engineered with traditional methods are unlikely to achieve full usability and user satisfaction. Still, many such systems are made by engineers using traditional methods. A complex device or instrument will fail in the marketplace if it is not usable by the customers. E-learning tools such as simulators and online experimentation will not lead to the desired learning effects if they are not engaging the students. One reason for this situation is that design thinking is typically not taught in engineering programs, and teachers of engineering courses are rarely trained in design thinking.

This study focuses on one aspect of design thinking, namely the achievement of quality through quantity. In most domains, quality is often viewed as the opposite of quantity in that quantity leads to poorer quality while quality is achieved through focus and low quantity (see, for instance, Becker and Lewis [1] and Motta [2]). It is thus a curious fact that designers often argue differently that quantity is needed to achieve quality. During ideation it is necessary to explore as much as possible of the design space thereby considering many poor ideas in order to discover the really good ideas. The claim that quantity is needed for quality thereby challenges the widely believed myth that quantity leads to poor quality. However, for someone with a basic understanding of design thinking the notion of quantity leading to quality is both intuitive and logical. Yet, we have been unable to identify any empirical evidence for this claim. The only exception being Keller and Staelin's study of the impact of information quality and information quantity for consumer decisions [3]. Other somewhat related studies include Shah, Smith and Vargas-Hernandez's [4] assessment of four metrics for measuring ideation, i.e., quantity, quality, novelty and variety, with the goal of assessing the effectiveness of different ideation techniques. Chan, Dow and Schunn [5] explored the claim that conceptually distant sources of inspiration is the most valuable for design processes. Their results supported the view that conceptual distance is not important.

This study is inspired by a text in the book entitled Art and Fear by Bayles and Orland [6] who gives the following account of an "experiment" to demonstrate that quantity leads to quality:

"*The ceramics teacher accounted on opening day that he was dividing the class into groups. All those on the left side of the studio, he said, would be graded solely on the quantity of work they produced, all those on the right solely on its quality. His procedure was simple: on the final day of class he would bring in his bathroom scales and weigh the work of the "quantity" group: fifty pounds of pots rated an "A", forty pounds a "B" and so on. Those being graded on "quality", however, needed to produce only one pot – albeit a perfect one – to get an "A". Well, came grading time and a curious fact emerged: the works of highest quality were all produced by the group being graded for quantity. It seems that while the "quantity" group was busily churning out piles of work – and learning from their mistakes – the*

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"quality" group had sat theorizing about perfection, and in the end had little more to show for their efforts than grandiose theories and a pile of dead clay."

Later, Buxton [7] discussed the same principle in the domain of user experience design with reference to the same text. It is not clear from Bayles and Orland whether this ceramics class actually took place or if it is just fictitious event constructed to help readers more easily visualise the point. This study thus set out collect empirical evidence based on Bayles and Orland's class experiment for a task of designing assistive technology to assess whether a focus on quantity leads to better quality in practice.

The implications of this study can be illustrated by revisiting the example of online experimentation. Online Experimentation (OE) [8, 9] involves learning through online and/or remote access to experiments. These can be virtual 2D and 3D simulations [10, 11, 12], augmented reality simulations or virtual reality simulations. Typically, such systems include various types of sensors at remote sites to make the simulation more real. Online Experimentation is often made available through collaborative web platforms [13, 14]. Typically, such a system will be engineered using the creators' first and best idea, and then improved in incremental steps until the result is satisfactory to the creators of the tool or framework. We argue that instead one should start more broadly and explore many possible ways of realising the online experience before committing to a particular approach. At each step the validity of the ideas should be tested on representatives from the target group (in this case students) thereby ending up with a more usable and engaging system that leads to improved learning effect among students.

II. Method

A. Experimental design

A between groups design was chosen with design approach as independent variable with the two the levels quantitative goal and quality goal and frequency of solutions as dependent variables.

B. Participants

The class comprised a total of $N = 106$ bachelor students in their second year (fourth semester) studying computer engineering, information technology and applied computer science. Most of the students were applied computer science students. The main difference between these study programmes is the amount of mathematics and physics in the curriculum where applied computer science has the least of the traditional sciences.

The class was divided into two groups according to the following criterion: As each enrolled student is assigned a running 6-digit student number, this number was used as filtering criteria. Students with an odd student number were to solve the problem with quality as the main objective and was named *yellow* project. Students with an even student numbers were to solve the problem with quantity of solutions as the main objective. This was named the *red* project. In theory there should have been approximately a 50/50 students solving red and yellow projects, however, there were 62 students (58.5%) in the yellow group and 44 students (41.5%) in the red group.

Most of the students in the class were in their 20s, while a handful of students were older. The gender balance was as follows: there were 16 females (15.1%) and 90 males (84.9%) in the class. Of these, 6 females (13.4%) solved the *red* project and 10 females (16.1%) solved the *yellow* project.

C. Task

The project was set as an individual assignment and conducted as their first hand-in in the course Human Computer Interaction, which is assessed using portfolios comprising one individual and two group projects.

Two separate problem descriptions were developed based on the same basic problem. The problem was to develop a concept for text entry using just one key [15]. The students were not given any pointers to the literature. This problem is easy to understand and narrow in scope, yet few students have been exposed to this problem before. A bi-product of working with this problem is that students get familiarity with design for diversity and marginalized groups. Another advantage of this problem is the large number of possible solutions with varying levels of quality.

The students assigned the *yellow* project were specifically instructed to develop the most efficient text entry method possible, while the students assigned the *red* project were specifically instructed to generate as many concepts as possible.

The students were also told to analyse their designs using MacKenzie's theoretical steps per character model [16] which uses the frequency of the alphabetic characters to estimate the average number of steps to input a character.

To balance the workload the students solving the *yellow* project also had to develop a working prototype and perform a simple usability test of their method. The projects were documented as written reports.

D. Analysis

The written reports were manually analysed during the assessment phase, and the approaches devised by the students were categorized into several classes and coded for subsequent analysis. Although the two methods were not completely identical, they were considered one category if the principles were sufficiently similar to the given input strategy.

The following main categories were identified: linear multitap where users press the button to move the letter forward one step [17], Morse code with long and short presses [18, 19], multitap with grouping, binary codes, binary search [20], Huffman codes as used in compression [21], knock codes (also known as Russian tap codes) [22], linear scanning [23], row-column scanning [24]. Morse code, Huffman codes and binary codes are considered impractical early stage ideas which are theoretically efficient from an information theoretic perspective, but impractical from a cognitive and ergonomic perspective as they impose high memory demands on the users. Multitap, multitap with grouping and knock codes are more practical as they rely on the visual system instead of memory, while linear scanning and row-column scanning are considered the optimal designs as they require little work and little demand on memory, but instead takes longer.

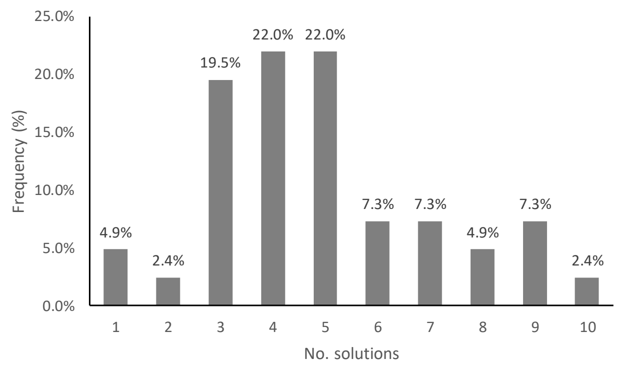

Fig. 1. Distribution of solutions generated by the students focusing on quantity.

These also represent the state of the art as assistive technologies used with switches for users having reduced physical function [25, 26, 27].

The data was gathered using Microsoft Excel and analysed using the open source statistics software JASP version 0.9.0.1 [28].

E. Ethics

This study was carried out during the autumn of 2017 before the introduction of the General Data Protection Regulation (GDPR). The identities of the participants were anonymized as the analysis described herein was conducted after the course had finished.

III. Results

As instructed, students focusing on quality reported on a single solution, while most of the students who were asked to focus on quantity generated more than one solution ($M = 4.9$, $SD = 2.2$). Fig. 1 shows the distribution of the number of concepts generated by the students that focused on quantity. Most of these groups produced 3-5 solutions. Only 4.9% documented just one solution while 2.4% of the students documented 10 concepts or more.

Fig. 2 shows the distribution of the different concepts for the two groups. As expected, the frequencies are higher for all the categories for students focusing on quantity. The entropy of the distributions (a measure of spread for categorical data) shows that the students focusing on quantity explored more solutions (*Entropy* = 2.84) than students focusing on quality (Entropy = 1.66). A contingency table analysis shows that these distributions for the wo groups are significantly different ($\chi^2(9) = 24.0$, $p = .004$).

Among the group focusing on quantity, 68.2% documented the basic multitap method, which was only documented by 25.8% of the student focusing on quality. Among the students focusing on quality, row/column multitap was the most frequently reported with 32.3%, while 36.4% of the other group reported similar techniques.

Fig. 2 also shows that among the methods that are considered optimal, 29.5% among the quantity group reported linear scanning, while only 3.2% ended up with the linear scanning concept among those focusing on quality.

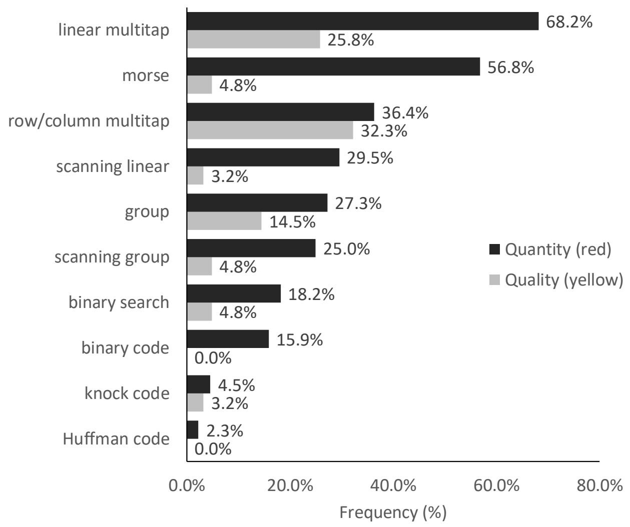

Fig. 2. Distribution of solution types

For what is considered the optimal solution, that is row/column scanning, 25.0% of the quantity group reported this method, while only 4.8% ended up with this concept among the quality group. These results thus agree with the claim that quantity lead to better quality than quality by itself. By focusing on quantity, the student had a 25% chance of detecting the optimal solution, whilst when focusing on quality the students had less than 5% chance of finding the optimal solution.

Each student in the two groups were assessed based on the objectives of the respective two problem descriptions. To confirm that the type of assignment would not affect the students grade, the grades of the two groups were compared. A Mann-Whitney U Test shows that the grades for the two groups were not statistically different ($W = 1127$, $p = .969$).

In order to identify any possible relationship between the quantity of solutions and the quality of the solutions, the quality of the solutions were categorized according to the following ordinal scale in increasing order of quality: 0: code based solutions (Morse, Huffman, binary), 1: binary search, 2: linear multitap, group, 3: row/column multitap, Russian tap-code, 4: linear scanning and 5: row/column scanning. The quality of the concept designed by each student/group was therefore represented by the solution with the maximum quality. This quality was then correlated with the number of concepts designed by the students. A Spearman correlation shows that there is a strong positive and significant correlation between quantity of solutions and quality of solutions ($r_s(44) = .514$, $p < .001$). The correlation is depicted in Fig. 3.

IV. Discussion

The results agree with the designers' belief that quantity leads to quality and disagrees with the technological belief that quantity reduces quality. Clearly, the claim that quantity leads to quality is specific to the context where one is seeking the solution to a new and unknown problem, the process which designers call design. Unfortunately, the term design is often used differently by engineers and technologists to mean solving a known problem with specific methods, i.e., such as designing the thickness of a weight carrying concrete beam.

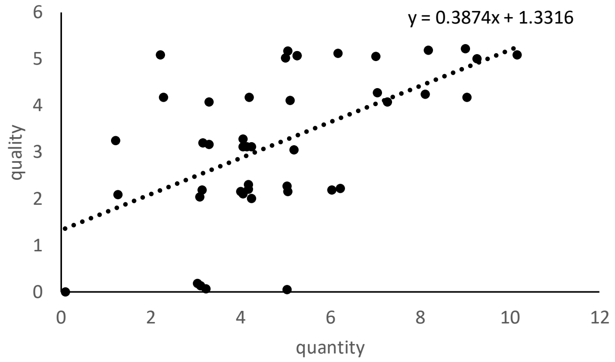

Fig. 3. Correlation between quantity and quality (with dithering)

Technologists, especially computer scientists often come across problems where there are no straightforward methods for finding the solutions. We therefore argue for developing engineers and technology students design thinking skills. One of the major challenges is not to make students delve into a technical solution too quickly but rather explore other options. One approach is to specifically instruct students to present several alternatives and to make students reflect over the quality gains through the process.

Another approach specific to computer science students is to impose a programming ban in a course, forcing students to find other ways to test out ideas, that is, low-fidelity prototyping with simple means.

It is our experience that the notion of design thinking is also not widely accepted among the more computationally oriented faculty members. One way to persuade such individuals about the benefits of quantity of solutions may be to draw parallels to stochastic processes such as Monte Carlo methods [29, 30, 31] and stochastic optimization [32, 33] where many pseudo-random solutions are generated by computers to find high quality solutions to complex problems.

This study evolved around a case involving the design of assistive technology for individuals with reduced motor function. This is just an example. The notion of quality through quantity can be applied to nearly any development process and target group, including platforms for online experimentation targeting students. We argue that adopting a design thinking approach to the development of online experimentation platforms where one refines an array of ideas instead of improving upon a single idea will lead to more engaging and effective learning experiences for students.

V. Conclusions

The paper described an experiment to explore the effect of emphasizing quality or quantity in a student design assignment. The results show that when students were asked to focus on quantity the resulting quality was better than when students focused on quality. The notion of quality through quantity is well established in the design disciplines while equating quantity with low quality is still a frequently believed myth within engineering and technological disciplines. Design thinking is increasingly important in order for engineers and technologists to solve tomorrow's challenges. Students therefore need to be trained to explore a larger portion of the design space before settling on a specific engineering solution.

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