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PHYSICAL PROTOTYPING TOOLKITS HAVE LIMITED EFFECT ON GROUP IDEATION IN DESIGN

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Abstract: First introduced more than 15 years ago, toolkits for prototyping are intended to facilitate rapid prototyping. These toolkits are often framed as means to support and speed up the creative process by allowing designers to quickly create and evaluate potential future products. However, little is known about how the introduction of prototyping toolkits influences group-based ideation and selection of ideas in the creative design process. To examine this, we carried out an experiment with 20 participants in 5 groups, in which two groups employed prototyping toolkits. Surprisingly, the introduction of a toolkit did not show any significant effect on participants' performances in the ideation and selection activities. The lack of effect is discussed in the light of the intended role of the prototyping toolkits.

Keywords: *Prototyping Toolkit, Design Process, Creativity*

1. Introduction

Can physical prototyping toolkits help design teams develop more creative design concepts? Within the field of interaction design and Human-Computer Interaction (HCI) several toolkits for physical prototyping have been introduced as means to ease prototyping in design processes. Often, these toolkits are used for group-based prototyping activities, in teaching and practice, e.g. when a design team employs them to co-construct and evaluate prototypes. There are a large amount of toolkits within the field of HCI; like Phidgets (Greenberg & Fitchett, 2001), Paperbox (Wiethoff et al., 2013) and Bloctopus (Sadler, Durfee, Shluzas, & Blikstein, 2015) just to name a few. Common for many of these toolkits is that they explicitly or implicitly are intended to overcome lacking technical skills amongst designers, which can lead to bottlenecks in creative design processes. Such bottlenecks manifest themselves in different ways, e.g. by shifting focus from design thinking to implementation thinking (Greenberg & Fitchett, 2001), (Hartmann et al., 2006), (Zehe, Grosshauser, & Hermann, 2012), or reducing the amount or quality of prototyping in early phases (Cottam & Wray, 2009; Wiethoff et al., 2013; Gehring, Hartz, Löchtefeld, & Krüger, 2013). One of the central motivations for developing and deploying prototyping toolkits is thus that they can help designers overcome these technical problems and lead to more rapid and fluent design iterations. The potential of the toolkits is thus framed as reaching beyond the challenges of constructing the prototypes to also improving the creative exploration and development of design concepts. Lending credence to this assumption, several contributions within the realm of screen-based interaction design have successfully overcome this bottleneck through the use of screen-based prototyping toolkits (Hartmann, 2009; Wiethoff et al.,

2013; Savage, Zhang, & Hartmann, 2012; Wiethoff & Gehring, 2012). This is in line with more general studies of design creativity, which posit that tools and materials influence how creative design processes unfold (Biskjaer et al. 2017).
Despite the growing number of physical prototyping toolkits, there has nevertheless not been any studies exploring whether or not they have the intended effect of creating a more fluent creative process in regards to group-based design. Two of the core components in creative design processes concern the *development and selection of id*eas, and in this paper we will focus on these two activities. While it is clear that the introduction of a prototyping toolkit directly affects the prototyping part of a design process (Greenberg & Fitchett, 2001; Hartmann et al., 2006; Wiethoff et al., 2013), it is still uncertain if and how a toolkit-induced enhancement of prototyping capabilities also affects other parts of the creative design process, in which ideation and selection of ideas are crucial components (Moggridge, 2007). We specifically examine how the *ideation* and *selection* phases are influenced by the use of prototyping toolkits for beyond-screen interaction, ie. toolkits for designing/building something that is not solely comprised of pixels.
The structure of the paper is such that we first provide an overview of prototyping toolkits, followed by an introduction to a model of the design process that entails the specific phases, including ideation and selection. Then, we present and discuss the experimental setup, the data analysis, and finally we present and discuss our findings in regards to the use and study of prototyping toolkits in creative design.

2. Related work

2.1. Prototyping toolkits

The verb prototyping involves the activity of realizing and testing a version or representation of a product before its actual existence (Buchenau & Suri, 2000; Floyd, 1984), and as a result, the goal of prototyping tools is to get to the point where realization, testing or experimentation is made possible. An early example of such tools is *Phidgets* (Greenberg & Fitchett, 2001d), a toolkit from around 2001 introduced as a response to hurdles they had been facing themselves in designing a tangible user interface: They found themselves focusing more on choosing, buying, soldering and programming components than on the design of the actual interface. The authors evaluated Phidgets with students and found that it eased the technical challenges that their students were facing with implementing an interface (Greenberg & Fitchett, 2001). The authors further point out that this easing frees up potential to focus on the design of interface – thus ensuring a more creative outcome (Greenberg & Fitchett, 2001f). The *Calder Toolkit* from around 2004 intends to lower the cost of an iteration and is tailored towards three key activities surrounding the act of prototyping: design exploration, design testing and data gathering and communication (Lee et al., 2004). Another example of a prototyping toolkit is introduced around 2005-2006 by Hartman et al. Named *d.Tools,* the toolkit is partly based on the notion that liberating the designer from thinking about implementation yields a better outcome by allowing more focus on what they refer to as *design thinking (Hartmann, 2009; Hartmann et al., 2006c)*. More recent toolkits are *Paperbox (Wiethoff et al., 2013e)*, *Bloctopus (Sadler, Durfee, Shluzas, & Blikstein, 2015)* and *WatchConnect* (Houben & Marquardt, 2015). The former was presented around 2013 by Wiethoff et al. as an effort to make possible early prototyping with tangible user interface (Wiethoff et al., 2013). The second focuses on the span that the authors point to exists between oversimplified abstractions offered by current toolkits and tools like Arduino that still needs e.g. programming or soldering skills (Lee et al., 2004). The latter addresses rapid prototyping of smart watches in the ecologies of surfaces and applications (Houben & Marquardt, 2015).

2.2. Ideation and prototyping

In order to facilitate the analysis of particular activities within the design process, we use Moggridge's model of the design process in which *Ideation* and *Prototyping* are distinct phases (Moggridge, 2007). This model is generally congruent with other commonly known representations of the design process such as Preece et al.'s (Preece, Rogers, & Sharp, 2015), which is based on four basic phases, and Löwgren & Stolterman's levels of abstractions (Löwgren & Stolterman, 2004). In line with these

models, Moggridge's model indicates that design processes often move back and forth between the stages, and they are reciprocally connected, so that a change in one part will influence other parts. The ideation phase is typically associated with divergence which is often considered a component of a creative process (Finke, Ward, & Smith, 1992). Furthermore, the performance of brainstorming groups is not a new topic of interest within creativity research, as evident from Stroebe et al.'s review on the topic (Stroebe, Nijstad, & Rietzschel, 2010). However, it is important for us to underline that divergent thinking is not the same as creativity "It's a cornerstone of creativity. But it's not all that creativity can be."(Kaufman, 2016, p. 91)

3. Method

Our research design builds on an experimental study of group-based ideation and selection, aimed at understanding the effect of introducing of prototyping toolkits in a design process. The work in this paper falls in the the category of *design studies* with the overall goal of explaining, understanding and producing knowledge about design as a general activity (Fallman, 2008). A rigorous research approach is central to this objective, understood as a transparent and systematic presentation of methods and argumentations, as well as a foundation built on on established research (Fallman & Stolterman, 2010).

3.1. Experimental setup

3.1.1. Participants

The experiment was conducted with in total 20 participants (5 female, average age 25.0). The participants included in the experiment all had practical experience in interaction design and 18/20 participants had completed a relevant education on bachelor level to the field. The participants were divided into groups of four and randomly assigned to being exposed to a prototyping tool (T) or not (NT). We opted for this group composition to determine how the introduction of prototyping toolkits would affect trained interaction designers, which is a group of users likely to make use of prototyping toolkits in real life.

Table 1. Distribution of groups/participants in different conditions

Toolkit (T)	No Toolkit (NT)
2 groups (8 participants)	3 groups (12 participants)

3.1.2. Process

The general process of the experiment can be described as a sequence of the following activities:

Table 2. Sequence of activities

Initial survey	*Toolkit explored*	Brief introduced	Ideation	Selection	Assessment & end survey	Discussion

The initial survey covering basic demographics was printed on an individual sheet of paper and was placed on the table in front of each participant. The toolkit was introduced to the participants in the randomly assigned toolkit group, who then spend time collectively exploring the functionality. Each individual participant was then handed the written brief, which is described in the following section. The ideation was 'one idea per sticky note' and followed a simple and three-round structure with an individual first round of exactly 120 seconds, a presentation round where individual ideas are presented to the group of approximately 3 minutes, and the final round of collaborative ideation of exactly 10 minutes. The selection was done in one round with no time constraint, with the goal of

deciding on the four best ideas. All ideas were grouped then group and individually assessed by each participant as per the parameters in the end survey, which was printed two individual paper sheets. E1 was initially conducted, documented and analysed, and E2 was then completed in the exact same manner.

3.1.3. Artifacts

The toolkit used in this experiment was the *littleBits: DIY Electronics For Prototyping and Learning* which "(..) puts the power of electronics in the hands of everyone.(..)." ("littleBits: Award-winning electronic building blocks for creating inventions large and small," n.d.-a) and "No soldering, wiring or programming required." ("littleBits: Award-winning electronic building blocks for creating inventions large and small," n.d.-b), this resonates well with the toolkits and underlying vision by e.g. Hartmann (Hartmann et al., 2006), Wiethoff et al. 2013 (Wiethoff et al., 2013) and Sadler et al. (Sadler, Durfee, Shluzas, & Blikstein, 2015; Wiethoff et al., 2013) The design brief used in the experiment was the *Student Design Competition* from CHI 2014 ("Student Design Competition : Call for Participation | CHI 2014," n.d.) and involved topics like the quantified self and has sensor technologies as a central point: "The growing design domain of the Quantified Self has been made possible through the integration of low-cost sensing technologies (..)" ("Student Design Competition : Call for Participation | CHI 2014," n.d.). The initial questionnaire was composed of questions regarding the participant's name, age, gender, and experience. The end survey regarded their individual and collective performance during the experiment using a Likert scale from 1-5 (worst to best). Ratings of idea novelty, quality, overall variation and overall group performance in regards to ideation and selection (the overall performance was not included in the analysis). It was noted that novelty '*of course, assumes different forms; Personal, contextual and historical, so try to make a personal overall assessment of each idea'* and quality '*consists of your personal overdue assessment of executability and possible effect in relation to the design brief*' whereas overall variation includes '*how you personally consider that the group has been able to uncover the design room adequately*' (translated from original). The questionnaire and the brief were printed on separate pages in order to reveal the right information in the correct order.

3.2. Analysis

The questionnaire was developed and included based on Shah et al. (Shah, Smith, & Vargas-Hernandez, 2003), who proposed *process* and *result* as the two basic dimensions to measure effectiveness in ideation. Evaluating the result as a measure of effectiveness does not cover all possible aspects of an ideation process, but given that good results are generated by a good process, the result-based measurement provides a tangible starting point in assessing the overall creative impact of the introduction of a toolkit. In regards to evaluating the results, Shah et al. point to four goals: *Novelty*, *variety*, *quality* & *quantity* (Shah, Smith, & Vargas-Hernandez, 2003). The aspects novelty, variety and quality are difficult to assess due to being both personal and contextual at the same time. One participant might find a given idea very novel - having never seen anything like it before - while the other participants might disagree. This was addressed by having all four participants in each session rate all ideas in that given session, averaging out possible biases in single Likert scale assessments. Similar approaches including the use of Likert scales are available in (Hartmann et al., 2006e; Wiethoff et al., 2013). The number of ideas per group were not included in the analysis considering the small number of groups. Between group average of these three aspects for each participant are analysed with unpaired t-test. The use of a t-test might raise some concern considering e.g. the ordinal character of the Likert scale, but this issue is unfounded and uncontroversial (Norman, 2010).

4. Findings

4.1. Quantitative inspection results

The survey completed by both the toolkit groups and no toolkit groups did not provide different effects based on the assessment parameters of the experiment.

Table 3. Mean assessments T+NT (Participants' self-assessments)

	T **Two groups** **(8 participants)**	**NT** **Three groups** **(12 participants)**
*Avg. idea novelty	2.79 (SD=0.46)	3.09 (SD=0.38)
*Avg. idea quality	2.91 (SD=0.39)	2.99(SD=0.30)
*Avg. variation	2.83 (SD=0.67)	3.08 (SD=0.64)

The analysis of the survey data indicates that *any effect caused by the introduction of a toolkit to the different phases and assessment parameters were either non-existing or not apparent* in the method and setup. The modest differences are yielding small t-values and thus insignificant results: avg. idea novelty: $t(20) = 1.522$, $p = 0.145$; avg. idea quality: $t(20) = 1.071$, $p = .0.298$; avg. variation: $t(20) = 0.694$, $p = 0.496$. This implies that *there is no observable effect on the participants performances in the ideation activities*. This runs counter to our initial assumptions, grounded in the literature on prototyping tools, which suggest that by helping designers overcome technical problems, this would lead to more rapid and fluent design iterations and provide better opportunities for creative solutions, of which ideation and selection are key components.

5. Discussion

5.1. The role and usefulness of prototyping toolkits

Based on the quantitative analysis presented here, we found that the use of physical prototyping toolkits did not influence the ideation and selection phases, neither for better or worse. This is surprising, since many of the toolkits have been described as having the potential to improve the creative processes, as outlined in section 2.1: Prototyping toolkits.

While our study showed no effects on ideation and selection, it may be that the toolkits simply missed the "sweet spot" in prototyping skills, where designers are neither highly skilled nor complete novices. This implies that a toolkit might affect ideation and selection if the designers had some experience or knowledge about e.g. prototyping with sensors actuators, but did not yet possess the skills to implement these without a toolkit. Further studies are needed to examine if this is the case.

Another possible explanation is that prototyping skills and the enhancement of these that follow from the introduction of a toolkit simply do not play a central role in ideating and selecting ideas. As previously mentioned, the initial study with *Phidgets* (Greenberg & Fitchett, 2001) showed how overall interface design considerations was promoted over electronic construction which might be a shift in activity characteristic within the same specific part of the design process. Perhaps the foci in the parts or the process addressed in this study are simply too different from creating and implementing prototypes. Buxton's clear distinction between sketches and prototypes might be exemplary in underlining the different foci: "(..) we must manage the sketching and ideation phase differently than we manage the back-end prototyping stage" (Buxton, 2007), p. 141). Following this, toolkits are perhaps relevant in regards to freeing designers from implementation thinking because they only intended for that. Had the prototyping toolkit been tailored towards overcoming conceptual hurdles the outcome might have been different. The tools we use can become embedded in the way we think, even when they are not in use.

5.2. Limitations

A potential shortcoming of this study lies in the limited statistical power of the experiment. Whether we are dealing with a type 2 error or an actual lack of effect in the sense is difficult to assess when dealing with a low number of participants. However, recruiting participants with relevant experience and education on a large scale would be very costly. Considering statistical power dependency on

sample size, magnitude of effect and statistical significance, we can estimate the experiments ability to detect effect sizes at 80% power and statistical significance at 0.05, with our variance and sample sizes at: novelty**:** 0.622, quality**:** 0.527, variation**:** 0.906. Simply put, we are only able to significantly detect changes and in each of the three characteristics if the magnitude is at least of the aforementioned sizes in either direction. Thus, there might be effects, but they are too small to detect in our study setup.

This leads us to consider the use-case and conditions of what we are studying, and raises the question of what effect we could reasonably expect from the implementation of a given toolkit. Since implementing a toolkit necessarily comes with some costs we need to consider what kind of improvements we are seeking? Is an increase in idea quality (ranged 1-5) from e.g. 2.8 to 3.3 worth implementing a toolkit for?

5.3. Further research

While the introduction of prototyping toolkits shows no discernible effects on group-based ideation in our study, we do not rule out that there are other effects, which we have not been able to identify in our research setup. The study at hand is based on the quantitative analysis of a distinct aspects of group-based creativity, namely ideation. While the aspects are clearly relevant in terms of understanding the creative aspects of the design process, there are many other aspects to examine. Moreover, qualitative analyses will likely yield further insights. Our next step is therefore to supplement the quantitative inspection with qualitative analyses of the experiment in order to better understand the findings, and to identify further patterns and dynamics in the design process.

6. Conclusion

On the basis of an experiment with 20 participants, in which some groups were provided with a physical prototyping toolkit, we have demonstrated that the introduction of a toolkit has no discernible effect on group-based ideation and idea selection. While this may seem like a null result, it comes as a surprise, firstly because the literature on physical prototyping toolkits suggest that they scaffold the creative process; secondly because screen-based toolkits have been shown to have positive effects on the creative process. While our findings have statistical limitations, they indicate the need for further studies of the effects of physical prototyping toolkits. Firstly, this will help establish a more nuanced understanding of the effects of these toolkits; secondly, it will help practitioners make informed decisions about when and how to employ such toolkits in practice.

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