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DISTRIBUTED EXPERIMENTS IN DESIGN SCIENCES, A NEXT STEP IN DESIGN OBSERVATION STUDIES?

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Abstract

This paper describes and proposes a new method for conducting globally distributed design research. Instead of using e.g. a software we tried out a completely analogue approach: Five carefully prepared packages, containing all the necessary materials and instructions for a design challenge, were sent out to supervisors in Norway, Finland, Italy, and Australia. These local supervisors then conducted the egg-drop exercise with students that are part of an international course held at CERN. As the task is conducted according to a previously tested protocol, the results gathered with this new method can then be benchmarked with this available data. This new approach to globally conducted engineering design activities avoids local bias and enables for gathering large amounts of diverse data points. One can also think of a research community where every member can send out one experiment per year and, in return, receives data points from across the world.
Based on the feedback from the supervisors we can say that from an organisational standpoint of view, this method works well. The comparison to the existing data has yet to be done.

Keywords: Research methodologies and methods, Crowdsourcing, Collaborative design, Prototyping, Globally distributed experiment

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1 INTRODUCTION

The paper describes the methodological approach of conducting parallel globally distributed experiments in design science and discusses the advantages and disadvantages of the approach. Besides tactical and analytical advantages, we strongly believe that these instruments may help to better ground the communities research in the science paradigm.

The last two decades saw an emergence of Design Observation Laboratories (Carrizosa et al., 2002; Törlind et al., 2009). The intent has been to conduct engineering design activities and to capture the activities as precisely as possible, mostly trough video and audio capturing. The aim was to identify and explore hypothesis and/or to run controlled and semi controlled experiments on the same (Tang, 1991; Tang and Minneman, 1991). These labs, such as the Design Observatory in Stanford and Luleå or the MEXICO Lab in Grenoble, have been quite successful in generating novel insights – however the setup and running of controlled experiments for example with a 2x2 matrix setup has been less successful. The key problems were:

1. The through piloting of such an experiments takes many rounds and months (space, activities, determination of depended and independent variables, determination of sensors and measurements, analysis preparation),
2. The need to obtain sufficient numbers of subjects that fit the stratified sample (40-80 minimum),
3. The duration of each experimental run (1-3 hours),
4. The potential of specific local biases (we are not sure if experiments conducted at Stanford with Stanford students would stand any closer scrutiny of external validity).

However, the advantages of controlled experiments and especially of confirmatory studies in multiple environments and by various teams are obvious and, at least in the positive sciences, uncontradicted. The current setup with empirical design researchers running complementary but not similar studies, in labs that are varying considerately seems thus not helpful.

In order to mitigate this problem and at the same time generate open access quantitative data sets, we propose a new method for global collaboration in design research that potentially offers an alternative to current approaches and subsequently avoids most challenges and shortcomings of global design studies: distributed experiments that encompass various global and cultural settings. This paper describes this new approach in detail and explains how we intend to benchmark and therefore potentially validate it.

Since this project is run in cooperation with the European Organisation of Nuclear Research (CERN) and the Challenge Based Innovation (CBI) initiates, we are also adopting the comprehensive authorship and open data requirements from CERN. All participants in the experiments are co-author of this paper and all data will be made available publicly. This is an experiment on conducting designs science experiments open and distributed on a global scale.

1.1 Challenges in Global digital Collaboration

With the rising importance of global collaboration, it became of great interest to create software environments that allow for easy communication between globally distributed Research & Development teams. Kolarevic et al. (2000) performed an experiment where students from different cultural and geographical backgrounds had to design a house together by only using a virtual design studio in order to communicate. Their findings suggest that the shared authorship in this kind of projects does not create a problem and that this kind of collaborations can work very well. However, with the introduction of a wide range of collaboration tools, such as digital whiteboards and a wide selection of software, managing global collaboration projects becomes a challenge (Chiu, 2002). Furthermore, a lot of groups propose different approaches to design collaboration research while many of them are focused on the digital component thereof (Cheng, 2003). Kvan (2000) raised the question of what exactly collaborative design is and comes to the conclusion that co-location simulations, such as videoconference systems, do not lead to better work product outcomes. Also, he proposes that people are actually co-operating and compromising rather than collaborating.

Not only the industry, but also researchers engage globally. Within the context of such research collaborations Cummings and Kiesler (2005) state that, on average, multi-university projects were less successful than projects located at only one university. However, a successful prior experience with a collaborator partially reduces the barriers of distance or interdisciplinary hurdles (Cummings and Kiesler, 2008).

1.2 Distributed analogue Approach

Instead of trying to find the perfect software for gathering data from all across the globe, we propose to use a completely analogue and decentralised approach. We prepared a design task (see section 2) in our research hub TrollLABS in Trondheim, Norway and shipped it in 30x35x12cm large boxes to three other universities. The experiments were then ran by colleagues who were informed beforehand about receiving a box and running a design task but were not told what this task will look like. As the same design task has been performed before, we can use the available results as a benchmark.

1.3 Hypothesis

Our hypothesis is that experiments can be conducted without the guidance of the researcher on location while the outcome stays the same and that experimental control assures valid data sets, large enough to run statistics and to identify potential differences based on subjects selection and cultural/educational background.

2 UNDERLYING DESIGN-TASK

In order to be able to benchmark the results from this distributed approach we chose to send out an already existing study that offers both, a detailed description of the procedure and a large set of reference data. Namely, we chose *the egg-drop exercise.* This design task, as introduced by Dow et al. (2011), challenges the participant to protect a raw egg from cracking after a free fall. The highest achieved drop-height of each participant is measured. Furthermore, the participants are separated into two groups: An iteration group that is allowed to test their prototypes and a non-iteration group which does not have the possibility of testing. As both, materials, and time for designing and building are limited, this experiment allows for quantifying the importance of prototyping during a design phase. The egg-drop exercise also requires the participants to estimate the height they will be able to reach before and after designing their vessel. These estimations are an indicator of the individual confidence level.

Additionally, we expanded this experiment by including two hypotheses, which are described in the sections below. A previously conducted proof-of-concept study suggests that these additions have no influence on the original procedure and the outcomes thereof (Kriesi et al., 2014).

We chose to send out the egg-drop exercise for the following reasons:

- It is a design task where the participant does not require any special education beforehand.
- The amount of material that has to be sent out is limited and fits in a 30x35x12cm box (for up to twenty participants).
- The experiment can be supervised without any specific knowledge beforehand.
- The procedure follows a clear structure that allows for sending out a checklist for every participant.
- Our group already has experience with conducting this experiment.
- There are previous data points available that can be used as a benchmark for this approach of globally distributing the experiment.

2.1 Additional Measurements

In a previously conducted proof-of-concept study we expanded the original egg-drop exercise by introducing a variable workspace setup. Furthermore, the participants were wearing an Arduino (ARDUINO, Italy) based sensor package that allows for recording acceleration and heart rate of the participant throughout the experiment.

2.1.1 Activity Level

Earlier studies have shown that stand-up meetings are more time efficient than sit-down meetings while the quality of the outcome is unaffected (Bluedorn et al., 1999). Further exploratory experiments held at NTNU and Stanford show similar results for prototyping and ideation sessions. Grounded on this knowledge we selected two prototyping conditions for the participants of the egg-drop exercise:

Half of the participants conducted the experiment while comfortably sitting in a chair while the other half only had the possibility to work while standing. The aim was to see whether or not this influences the number of tests the participants in the iteration group conduct throughout the design phase.

2.1.2 Physiological Data Acquisition

During the experiment the participants have to state their confidence level twice: Once before designing the vessel and once after having built the final design. The results show that participants of the iteration group experience, in average, an increase in their confidence level, unlike the members of the non-iteration group. Their confidence level stays constant, or in other words, they do not know more about their design than at the beginning. Research has shown that uncertainty can induce stress in humans (Greco and Roger, 2003; Pruessner et al., 1999). One sign of an increase in the stress level is an increase of the heart rate (Appelhans and Luecken, 2006). Based on these facts we decided to record an electrocardiogram (ECG) and the acceleration of the participants throughout the experiment. The ECG can be used to extract the heart rate and in combination with the acceleration values it is possible to distinguish between physical and psychological factors for an increased heart rate. During the interview at the end of the experiment the participant is challenged with questions regarding the design of their vessel. The goal was to see whether or not it is possible to detect a difference in their heart rate at the beginning and at the end of the interview as this can indicate a difference of the stress level (Kriesi et al., 2014).

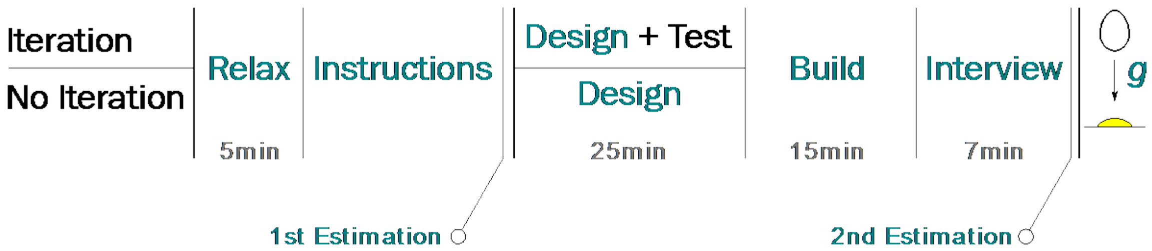

Figure 1. The procedure of the egg-drop exercise.

2.2 Procedure

Expanding the original procedure, a relax phase was introduced at the beginning of the experiment in order to investigate the additional measurement mentioned in section 2.1. Based on the experiences of our previous proof-of-concept study we changed the length of the interview (Kriesi et al., 2014).
After signing a statement regarding the voluntary participation in the experiment, the participant attaches three electrodes to his body and subsequently to the ECG unit of the sensor package. In order to get a reading of the resting heart rate of the participant, they then watch a five-minute video that helps them relax. Only then the participant is confronted with the instructions to the egg-drop exercise, the set of materials that is available for the final design, and the drop zone where the final test is conducted. Figure 1 graphically describes the procedure of the experiment. One complete set of materials consists of the following elements (also depicted in Figure 2):

- 8 pipe cleaners
- 8 rubber bands
- 8 popsicle sticks
- 1 10x20cm poster board
- 1 10x15cm flat foam
- 1 sheet of tissue paper
- 30cm scotch tape

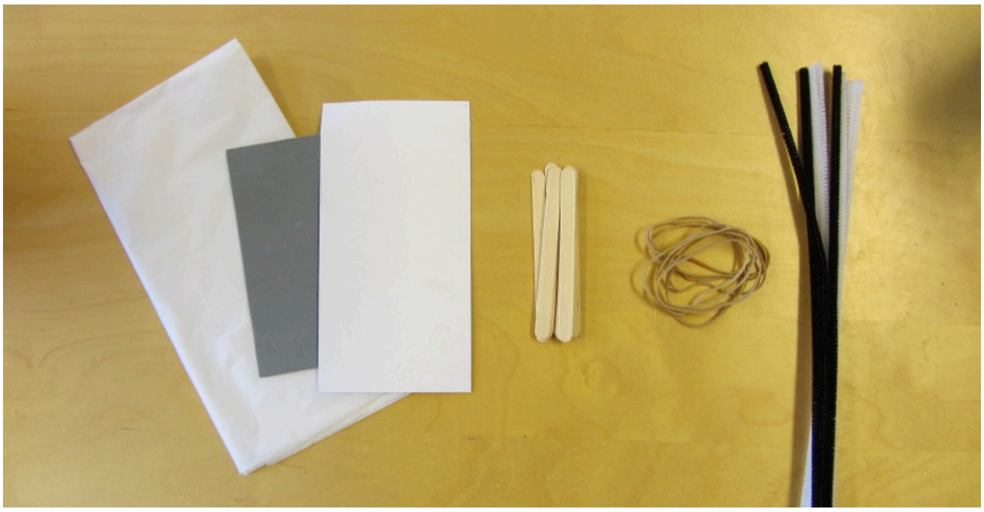

Figure 2. One Set of Materials: (FLTR) Tissue paper, flat foam, poster board, popsicle sticks, rubber bands, pipe cleaners (scotch tape not shown).

Based on this information the participant is then asked to make a first estimation of the final height they can achieve (noted as *confidence level before*). The participant then has 25min to design a vessel that protects the egg. During this phase a member of the iteration group can test as often as they want to. Once the time is over the participant gets one fresh set of materials and 15min time to build the final design. Before performing the final test of the device the participant has to explain their design in an interview with the supervisor and give a second estimation of the final height (noted as *confidence level after*). The questions asked become increasingly specific throughout the interview in order to provoke stress due to uncertainty in the participant. The last part of the experiment is the test where the vessel is dropped from increasingly high levels (increments of 30cm) until the egg cracks. The maximum height the egg survives without taking any damage is the final score.

2.3 Results for Benchmarking

This section presents the results that we will use in order to benchmark the results we are gathering from the globally distributed experiment. The results are from two independent studies: The first one was conducted by Dow et al. (2009) with twenty-eight students. The second one, a proof-of-concept study, was conducted by (Kriesi et al., 2014) with thirteen participants. It followed the same protocol and investigated the additional measurements described in section 2.1.

2.3.1 Drop Height and Confidence Level

The results of from Dow et al. (2009) are listed in Table 1. The key findings are that the iteration group reached in average an 85% higher final drop level than the reference group. Furthermore, the iterating participants showed an increase of 44% in their confidence level, whereas the non-iteration group showed no change thereof.

Table 1. Given results: Highest drop height reached and the confidence level before and after designing and building the device. Data from Dow et al. (2009).

		Non-Iteration	Difference		**Iteration**
Final Height		101cm	+85%		186cm
Confidence Level	Before	95cm	+0%	+44%	125cm
	After	95cm			180cm

The second study conducted by (Kriesi et al., 2014) confirmed these results as shown in Table 2. The additional findings regarding the activity level and the physiological data acquisition as described in section 2.1 were that the standing participants of the iteration group tested 33% more often than the sitting counterparts. Also, the iterating participants showed in average a decreasing heart rate (-2.1%) throughout the interview, whereas the heart rate of the non-iterating participants increased by 6.8%.

These numbers can indicate a decrease and increase, respectively, of the individual stress level. As the number of data points was small, the numbers from the second study should be interpreted as trends.

*Table 2. Given results: Highest drop height reached and the confidence level before and after designing and building the device. *Three participants in the non-iteration group tested their prototypes on the table during the design phase and subsequently cracked their eggs. Their official result therefore was 0cm. The value in brackets is calculated with the heights they reached with a replacement egg. Data from Kriesi et al. (2014).*

		Non-Iteration	Difference		**Iteration**
Final Height*		69cm (103cm)	+154% (+70%)		175cm
Confidence Level	Before	141cm	-3%	+18%	135cm
	After	137cm			160cm

3 GLOBAL IMPLEMENTATION

A local supervisor on location performs the experiment that is described in section 2 with the participants. The focus of the preparation therefore lied on making the content of the packages self-explanatory and the instructions as simple and clear as possible for this local supervisor. Only the following items had to be organised by the supervisors on location:

- Workspace
- Chicken eggs
- Scissors
- Stop watch

3.1 Packages

As described in section 1, our goal was to perform the experiment completely offline. Subsequently, all the materials and instructions had to be enclosed in the boxes. Figure 3 gives an impression of the preparations. The following sections explain the different elements that were shipped.

3.1.1 Materials

To ensure that all participants have the exactly same materials we prepared four complete sets (see Figure 2) per participant on location. Additionally, we prepared a measurement tape for the drop zone so that every test is conducted from the same height levels.

Figure 3. Impressions of the preparation of the packages. All the materials (left) and batteries (right) were shipped in clearly defined amounts.

3.1.2 Sensor Equipment

A sensor unit is necessary for the physiological data acquisition as it is described in section 2.1.2. Our solution is based on the microcontroller Arduino Uno. The voltage reading from the skin is amplified (x300) by a CookingHacks eHealth Shield (LIBELIUM COMUNICACIONES DISTRIBUIDAS S.L., Spain) and results in the ECG data. An accelerometer from Sparkfun (SPARKFUN ELECTRONICS, CO, USA) registers acceleration in all three axis directions. All the data is stored on a microSD card that is accessed by using a Sparkfun microSD shield. Figure 4 depicts the sensor units and the acrylic boxes they were shipped in. A battery powers the sensor unit and one for each participant was shipped in the box. Exchanging the battery was made easy by attaching Velcro tape on both, the battery (see Figure 3 on the right) and the sensor casing. The supervisors were instructed to replace them after every participant in order to ensure that no sensor runs out of power during an experiment. Wearing the sensor unit was made easy by adding an adjustable belt to the casing. Enough electrodes for each participant were shipped as well.

3.1.3 Videos and Data Carrier

In order to get the instructions across in a simple manner we decided to focus on the usage of videos in addition to written documents. A total of seven videos were created, each with a specific topic. An introduction video explains the supervisor the design task itself and one video explains each item that they find in the box. For the participants there is one video that instructs them on how to attach the sensor unit and one for each phase of the experiment: Relaxing phase, design phase (two versions for both, iteration and non-iteration group), and build phase. The videos were delivered on a USB stick that contained a folder for each participant and the supervisor. As there were different versions for the iteration group and non-iteration group this structure ensured that each participant was shown the right video.

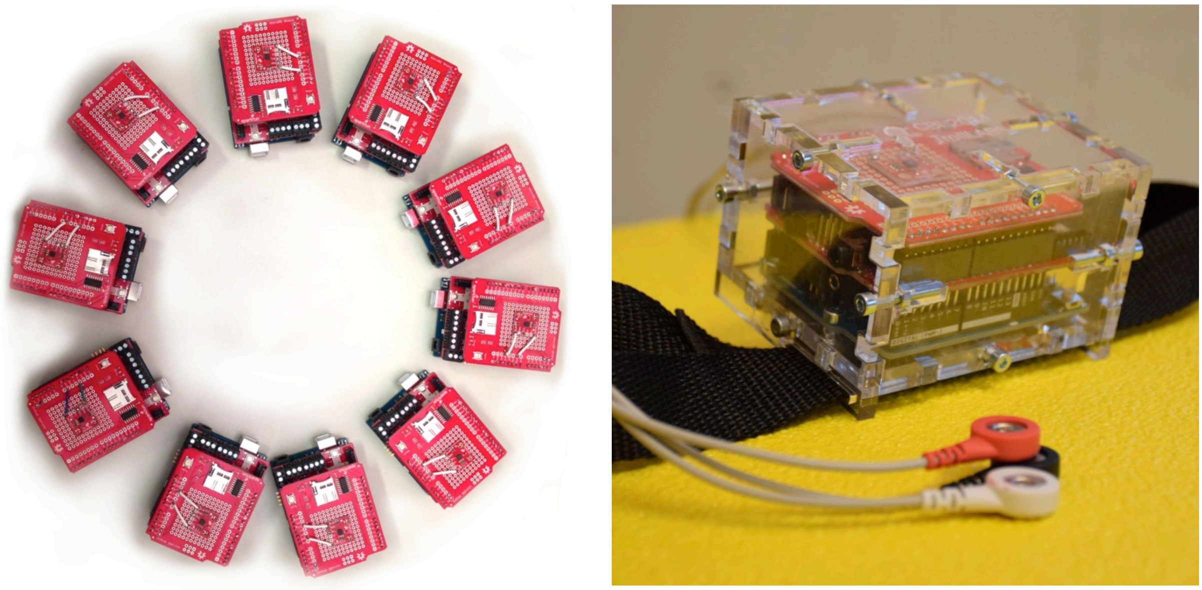

Figure 4. The ten identical sensor units (left) that were shipped in acrylic boxes (right). An adjustable belt allows for easy wearing around the hip.

3.1.4 Checklists and Envelopes

In addition to the videos the supervisor also got an envelope for themselves and one for each participant. For the supervisor this contained a welcome letter and instructions on how to proceed with the USB stick and what they have to prepare. The ones for the participants included the instructions for the experiment and, most importantly, a participant specific checklist. This checklist for the supervisor not only contained the information regarding what setup each participant needed (sitting/ standing, iteration/ non-iteration) it also guided them step by step through the whole experiment. The supervisor had to tick off all the steps, write down important numbers (e.g. drop height) and sign the document at the end. Figure 5 contains an excerpt from a checklist that was sent out.

3.2 Participants and Shipping

For the second time members of CERN organized a class called CBI. The aim of this course is to let the students find a way to bring technology that was developed at CERN into different fields of application than particle physics. Furthermore, the students are forced to collaborate globally as they are located in Melbourne, Australia; Helsinki, Finland; Reggio Emilia, Italy; Barcelona, Spain; Trondheim, Norway. As the students have to present a functioning prototype at the end of the class, the egg-drop exercise is a great tool to show them the importance of iterating ideas. Furthermore, their coaches on location are ideal for supervising the globally distributed experiment. It has to be noted though that none of the supervisors knew beforehand what task they receive in the box. As the student coach in Trondheim was also preparing the experiment, another member of the group, who was not previously involved in the process, conducted the experiments.
All boxes were shipped with a private postal service in order to guarantee fast and save delivery.

14. 3 minutes break ☺ ☐

<u>INTERVIEW (7 minutes):</u>

15. Start interview and follow interview protocol. Feel free to add questions If it is written -this part-, then just ask about any specific part that you see in the participants design: ☐
    Write down time shown on stop watch: ______________________
    - Questions for minutes 0-2 (general design questions):
        - Please explain me the functional parts of your final design.
        - Explain from inside out (egg to outside) how you built up the design.
        - Is there a thought behind the colour of -this part-?

Figure 5. Excerpt from the checklist that was sent out. It guides the supervisor step by step through one experiment.

4 CONCLUSIONS

From this first iteration of running a globally distributed experiment we can conclude that creating and running the procedure leads to many advantages for the research group. It starts during the preparations of the experiment: The level of detail needed is higher than when running the experiment locally. All instructions have to be on point and easy to understand by any local supervisor that does not know the procedure beforehand. Only by re-enacting the experiment many times and by observing how unprepared members of the group handled the instructions we were able to achieve the desired level of detail. At the same time we gained deeper knowledge about the key factors of the experiment and the setup thereof became more robust. Based on the feedback that we gathered from the coaches who have conducted the experiment, the preparations worked out very well for this first trial. The second major advantage for the research group is the amount and the diversity of potential data sets. This distributed method allows for collecting multiple sets of data points at various locations in parallel. Subsequently, large enough data sets that allow for in depth statistical analyses can be gathered faster. Performing design studies all across the world also means that these data sets have larger validity. The broader set of participants also reduces local bias within the data set and can reveal specific local tendencies at the same time. As Sue (1999) points out, theories and principles may or may not be generally true, however they require evidence and cross-validation to become universally applicable.
We can further conclude that future globally distributed experiments need a very strong focus on the managerial side. Not only did the preparation for shipping become unexpectedly time consuming, also the scheduling of the experiment turned out to lack organisation. It is therefore necessary for further iterations of the distributed approach to stay in very close contact with all prospective collaborators long before the experiment actually begins. Just like with any group of participants one has to anticipate that some collaborators change their minds within the last second.

5 OUTLOOK

In case the results returning from this globally distributed design experiment match the ones from earlier studies (Dow et al., 2009; Kriesi et al., 2014), this method opens up a whole new world of gathering data points in design studies. It would no longer be necessary to either travel to various locations or find one academic or industrial partner that is willing to provide many participants. This can enable smaller research groups with limited financial possibilities to create global research projects as well. As for recruiting participants, similar to sending out questionnaires, many locations could provide a few data points each. Furthermore, one could create a global network where each member has the right to send out one design task per year to all other members. Each location then individually has to conduct the experiment on site and sends back the results. One can also imagine introducing the tradition of confirmatory studies into the field of design research. Experiments that are described in detail can potentially be repeated at large scale without too much effort on location. Additionally, research groups can benefit from iterating pilot studies in a timely manner before running the final experiment with the help of industry partners. Carver et al. (2003) come to the conclusion that such pilot studies are not only beneficial for researchers but can offer great educational potential.

Enabling studies across multiple locations within one industry could further be beneficial for the industries themselves. One can imagine that culturally specific engineering design methods are just as important as culturally specific management skills. The latter have been subject to intensive studies (Hofstede, 1984) and as Hofstede (1994) points out, the structure within multinational companies should ideally follow the culture.

We would like to point out that during the process of writing this paper we already found three universities who are interested in participating in such a research network and who are currently performing a design study that we sent to them.

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