A Spatial Informance Design Method to Elicit Early Interface Prototypes for Augmented Reality

Joe Cowlyn, Department of Computer and Information Sciences, Northumbria University, Newcastle upon Tyne NE1 8ST, UK, joe.cowlyn@northumbria.ac.uk

Nick Dalton, Department of Computer and Information Sciences, Northumbria University, Newcastle upon Tyne NE1 8ST, UK, nick.dalton@northumbria.ac.uk

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Abstract

Designing for augmented reality (AR) applications is difficult and expensive. A rapid system for the early design process of spatial interfaces is required. Previous research has used video for mobile AR design, but this is not extensible to head-mounted AR. AR is an emergent technology with no prior design precedent, requiring designers to allow free speculation or risk the pitfalls of 'path dependence'. In this paper, a participatory elicitation method we call 'spatial informance design' is presented. We found combining 'informance design', 'Wizard of Oz', improvisation, and 'paper prototyping', to be a fast and lightweight solution for ideation of rich designs for spatial interfaces. A study using our method with 11 participants, produced similar and wildly different interface configurations and interactions for an augmented reality email application. Based on our findings we propose design implications and an evaluation of our method using spatial informance for the design of head-mounted AR applications.

1 Introduction

In recent years augmented reality (AR) and virtual reality (VR) have seen a rapid increase in the availability (ARCore (2021), Oculus (2021)) and capability of new devices (ARKit (2021), Qualcomm (2021)). Virtual and augmented reality (and the blanket term XR or Extended Reality (2017)) offer a wide range of interface affordances, which present challenges when designing for such applications.

Head-mounted XR systems have until recently focused on the properties and affordances such technology creates (Van Krevelen & Poelman, 2010), instead of the needs and goals of the user (Dünser & Billinghurst, 2011). Head-mounted AR devices are increasing in number from the HoloLens (2021) released in 2016 to multiple devices such as Magic Leap (2021), Varjo XR-1 (2021), Nreal Light AR (2021), and others (*The Ghost Pacer*, 2021; *Tilt Five - Tabletop AR*, 2021; *XRSPACE*, 2021). Each of these devices have different input methods, spatial scanning capabilities and granularity, resolution and field of view, and recommendations for the use of each.

Recently there have been several developments looking towards productivity in VR (Gesslein et al., 2020) and AR (Li et al., 2019). These are spatial interfaces that use XR hardware but are agnostic to the physically located environment. They also reuse past WIMP style input paradigms of legacy desktop and mobile systems in the virtual realm (Jetter et al., 2014). Such systems seek to exploit XR for text centric knowledge work (Grubert et al., 2018).

A popular choice for creating content for XR is to use a game engine such as Unity (2021) or Unreal (2021), which introduces specialized programming and 3D asset creation requirements. While this has many advantages in producing a final product or high-fidelity prototype, a lot is lost in the ability to easily modify and adapt to changing ideas of stakeholders as can be done with low-fidelity prototyping.

This has created the need to better understand the design of such user experiences. This is especially true in the case of fully context-less AR such as for spreadsheets or big data analysis, which deal with abstract information but have no inherit locations to take advantage of. This kind of location independent virtual office style system currently has no fixed standard for interaction, creating a gap in knowledge about how to design for them. When approaching potential users, we have currently all the advantages and disadvantages of dealing with an emergent system. The central problem being when the user is totally unconstrained, it raises the question of how they will begin to ideate potential interfaces and interactions with a system unlike any which has been previously possible.

We currently stand at a vital moment for these systems, with the potential for creating a truly natural UI from user elicitation studies before users become strongly influenced by prior precedent.

By using user participation at this early stage, we maximize the possibly of creating a natural and intuitive UI. This inclusion of users in the design of interfaces at the early stage also has the potential to avoid embedding long-term usability problems which could be carried on as a legacy cost into the future. This cost is what Economists term ‘Path Dependence’ (Liebowitz & Margolis, 1995).

This paper aims to develop prototyping methods for user participation in the design of head-mounted AR, to minimize early mistakes and elicit novel interface interactions to avoid 'path dependence' and promote the design of intuitive interfaces.

2 Related Work

2.1 Augmented Reality Prototyping

Nebeling & Speicher (2018) gives a good overview of the difficulties of current AR authoring tools. In 2011, de Sá et al. (2011) introduced basic mobile AR prototyping using video processing and situated 'guerilla evaluation' techniques, evaluating an interface in the intended environment with passersby. They found video for AR design promoted user participation and triggered imagination for features and usages, but some affordances and features were not easily perceived through video. Other researchers have also explored low fidelity prototyping for augmented reality using video processing methods such as Pronto (Leiva et al., 2020), ProtoAR (Nebeling et al., 2018) and 360proto (Nebeling & Madier, 2019).

ProtoAR was introduced by Nebeling et al. (2018) in an effort to extend existing tools like DART (MacIntyre et al., 2004) for the construction of AR interfaces without the requirement of programming expertise. ProtoAR uses Play-Doh and paper to create props in a mobile AR experience. The authors' objective was to rapidly construct mobile

AR application prototypes to both explore possibilities in design and to provide artifacts for user feedback.

Hampshire et al. (2006) describe a taxonomy of AR authoring frameworks primarily focused on low-level programming interfaces and high-level meta structures, addressing different levels of abstraction. This is mainly focused on prototype implementations of an AR system.

However, these systems have been largely aimed at handheld/mobile augmented reality, which rely on the use of both tangibles and touchscreen interfaces. The implicit assumption is that design decisions are also extendable to head-mounted AR. It should also be noted that by introducing a screen, an extensive library of prior design methods is made available. These systems also tend to focus on the needs and limits of the technology, rather than beginning with the needs and potentials of the user. This work points towards something which is cheap, fast to prototype, easy to revise, and exists well enough in the real world to scaffold the imaginations of non-experts, while allowing articulation of their vision.

2.2 Low Fidelity Prototyping

One classic methodology used in many 2D interaction design scenarios is that of ‘paper prototyping’. ‘Paper prototyping’ (Snyder, 2003) uses paper mock-ups that are cheap and quick to construct and equally quick and easy to change.

This allows participants to rapidly understand the purpose of the prototype and are not inhibited to suggest changes to a design (Beyer & Holtzblatt, 1999; Sefelin et al., 2003). Paper prototypes however assume some screen-based activity which can be simulated by the paper. For wholly new interfaces ‘paper prototyping’ requires multiple prototypes to be selected between, such as with the defined concepts mentioned by Ciolfi et al. (2016).

Another means that can be used to prototype a low-fi system is to use microelectronics coupled with cardboard and conductive materials (Bowers et al., 2020; Hudson & Mankoff, 2006; Pedersen et al., 2000; Wiethoff et al., 2012), cardboard and mirrors (Broy et al., 2014) or projected overlays (Akaoka et al., 2010; Burns et al., 1994). However, these methods require specialized software, hardware and/or materials.

Other methods such as ‘Wizard of Oz’ (Kelley, 1984), a process which allows the interactions of an interface to be generated by a human rather than by a computer, can be used in conjunction with low-fidelity prototyping to allow for increased simulated functionality (Säde et al., 1998), which can be as effective at discovering design errors as using a similar high-fidelity system (Virzi et al., 1996).

After investigating the above previous methods used for augmented reality prototyping, it was clear something simpler was required, without the need for any hardware or software.

These methods lead to using ‘Wizard of Oz’ over implemented design details as it allows for implementations of an interface to be tested out without any need for any complex recognition or emulation using software.

‘Paper prototyping’ could also be easily used alongside ‘Wizard of Oz’ as a blueprint for how to simulate a functional system with simple materials which is also easily able to be altered to accommodate changes on the fly. We also felt the methodology of ‘paper prototyping’ had the potential to simulate more than just 2D interfaces and that the cheap materials could easily be extended to simulate a 3D environment in an AR headset.

2.3 Bodystorming, Participatory Design and Embodied Ideation Methods

Looking to a different history of design solicitation in the expert domain, we find ‘bodystorming’ (Oulasvirta et al., 2003). ‘Bodystorming’ was originally designed as a practice to break down some of the barriers in traditional brainstorming. What made early ‘bodystorming’ research practices significant is the emphasis on a representative environment. The objective here was to be able to view proposed ideas in the right social and spatial context in which the final product will be used. It was quickly recognized that ‘bodystorming’ was naturally an embodied form of the ideation process, which seemed a natural fit for application design of ubiquitous devices.

Segura et al. (2016) later refined this work to create what they called ‘embodied sketching’ this was partly done with the use of prior prototypes. This work was then developed into ‘embodied storming’ (Schleicher et al., 2010) and ‘experience prototyping’ (Buchenau & Suri, 2000). These use an actor with scripted behaviors to help designers develop the system. It seems that most of the methods working under the banner of bodystorming typically operate around a group of expert designers looking to maximize their empathy with users and do this primarily via seeking spatial and/or situational fidelity. For the process of designing for a location-free AR system based on user participation these methods, while attractive, are designer centric but point to the possibilities of a more embodied approach reflecting the nature of AR.

2.4 Use-case Theater and Informance Design

Intertwined with bodystorming approaches have been a number of theatrical techniques including ‘use-case theater’ (Schleicher et al., 2010) and ‘forum theater’ (Hine et al., 2012), which involve prototyping the space and place of a product’s use by employing living personas or actors and props. Hine et al. (2012) used ‘forum theater’ to elicit design feedback from older adults by drama-based scenarios, which predominantly focused on the social activities of the technology presented. Iacucci et al. (2002) discussed various cases of performance used in design and inferred three roles of performance in the design of interactive systems: exploring, communicating, and testing.

The ‘use-case theater’ and ‘forum theater’ methods reach back to ‘informance design’ (Burns et al., 1994), which was itself an extension of ‘bodystorming’ (Oulasvirta et al., 2003). ‘Informance design’ explores design ideas in a way which is generative rather than analytic. Here the word ‘informance’ is a portmanteau of information and performance. ‘Informance design’ consists of the performance of a scene before an audience of peers and clients. These scenes are based on characters (or roles) which are identified by observation and interview. A script is written through a process of improvisation by the ‘actor’/designers and possibly others. Design occurs primarily during rehearsal for both prototype and performance. A number of scenes are presented to the audience, promoting reflection and appropriation which can then be used in later participatory design sessions. The original user study for ‘informance design’ used ‘Wizard of Oz’ and a GUI blended with a camera feed to simulate a “smart mirror”, with actors to roleplay dialog between them in a simulated hairdressing setting.

The ‘informance’ method fulfils many of the needs of a design for a system without legacy, specifically it could be used as part of a participatory design method. It was a mechanism which could be used both for user elicitation and then for analysis such as is common in ‘paper prototyping’.

Our primary contribution for this paper is a new method of user elicitation based on a refinement of ‘informance design’ expanded with participatory design for the spatial case of augmented reality.

This new method will be presented along with an example use case to evaluate the method and specific findings will be presented for the design of an augmented reality email system.

The rest of this paper will describe the method we have refined and then go on to describe a case study, results, and design implications.

3 Method

While prior experience with paper prototyping made us believe it was possible to work with such 'imaginary' interfaces, we were worried if it was possible to do paper prototyping in three-dimensions. We strove to build upon previous work to make a system, using facilitators improvising system functionality, of a concrete live three-dimensional 'living sketch'. Using improvisational techniques participants actively engage in the enacted scenario in a three-dimensional way with their own ideas. This helps both scaffolding the user's imagination and with allowing them to communicate their vision with the facilitators and ultimately designers. From our experimentation, we iterated on this process generating the following elicitation methodology we call 'spatial informance design'.

Our method differs from 'informance design' by focusing on the improvisation session and recruiting peers and clients to take part in them. We maintain the same use of space and environment to promote context for the growing empathy between designer and client. We also use scenes, but in this context they operate like use cases with multiple use cases used per session. The process of reflection and appropriation happens during the improvisation process and with a stronger focus on recording and analyzing individual participants' experiences retrospectively.

We will now provide an in-depth description of our methodology.

3.1 Methodology

3.1.1 Domain

The methodology begins with a preparatory phase identifying the application to be envisaged. The domain must be familiar to users which either requires prior knowledge or a briefing on the nature of the problem. Our aim was to create the outline of a design for an augmented reality based electronic mail program. This was chosen as it would be a familiar task to all of our participants due to its ubiquitous use in current desktop and mobile environments and of an interest in a possible solution for email overload (Whittaker & Sidner, 1996) using augmented reality.

3.1.2 Spatial Context

The basis for our method was to begin by operating in a specific spatial context, such as is found in 'bodystorming'. In our case study, this was an unused room with a number of chairs and tables available. This would simulate our office or knowledge work in context.

3.1.3 Seeding

Figure 1 Here

It is necessary to seed the experience to give the impression of a three-dimensional user interface. In our specific case, we did this by creating what we called a “washing line display”. This consisted of a string connected across two pillars in the room, along which were attached a number of printed emails (see Figure 1). Other seeded elements we included were a secondary washing line to act as a “storage zone”, an A3 sheet containing an email template (see Figure 2), a printed calendar, a set of cardboard tubes labeled with possible contacts, a physical keyboard, and a laser pointer.

Figure 2 Here

Seeding could also be artifacts that previous participants had created (see “Inbox” control on pillar and “post box” on table in Figure 1). As part of the initial briefing, it was important to establish with the participants that the seeding was simply an imaginary starting point and could be removed or adapted to their suggestions. The idea here was not to create a functional prototype, but more provide potential scaffolding for the participant’s imagination. This can be seen like set dressing; participants are located in a real room but representations of virtual objects such as the washing line are an imagined 'virtual projection' from the AR equipment.

Figure 3 Here

Seeding was felt necessary, as it helped set the scene and tone of the low fidelity paper prototyping. The seeding also helped overcome the ‘blank page’ situation of having no initial starting point. While no seeding would have offered the possibility of eliminating prior agendas/conceptions, this was at the loss of other complex factors. In the end we decided to include limited seeding to help scaffold the playful augmented-reality-in-reality nature of the process. However, we were also very conscious of the role of seeding and used the study to examine its impact as will be discussed in the evaluation (see Section 5.1).

Additional to the seeding of the original environment, we allowed seeding of ideas from previous participants to be propagated forward to iteratively offer interesting or novel ideas.

3.1.4 Individual Participants and Facilitation

The core of our method is to introduce a scenario to participants individually, for our case study of an augmented reality email program, and then explain and possibly demonstrate the improvisational method. That is, the participant would act out their intended actions and the facilitators must endeavor to best realize those actions (see

Figure 3). For example, if a participant announced the appearance of a dialog box, the facilitators would pause the interaction, draw a dialog box on card and negotiate with the participant the nature of intended features such as title and buttons. The interaction would be restarted with the facilitator holding the dialog box up in the air for the participant to decide upon an interaction. It was possible for the facilitator to further probe and question the participant during the improvisation or after. For example, they might ask if there is the existence of a cancel button or if an action was canceled, what might occur in response.

3.1.5 Improvisation

It was made clear to participants that the scenario was purely brainstorming and that anything was allowed. Inspired by ‘Wizard of Oz’ approaches, the facilitators being aware of the underlying technological difficulties, must probe for alternatives when a user requested some technology which might be challenging to create. In practice it may be necessary to inform participants of false constraints concerning what could be possible with technology. The improvisation provided a number of points which allowed the participant to imagine and discuss the spatiality and dimensionality of the application. As in ‘paper prototyping’, during the interaction the participants were encouraged to use the ‘think aloud protocol’ (van Someren et al., 1994). Participants were always free to “pause” the augmented reality and engage in conversation with the facilitators to clarify the task or any other purpose. The essence of the improvisational process is to use physical objects (props) as stand-ins for the virtual objects or alternatively as the physical objects themselves. Best practice would be to clarify with participants the intended state of objects within their imagined AR system, as to whether they are intended as real or virtual. For example, a physical keyboard “prop” can serve as either a real physical keyboard or an imagined virtual keyboard. The facilitators exist to animate the props as might be expected in a user interface.

3.1.6 Initiation and Tasks

For the experiment participants were asked to wear an eye-tracking camera (Tobii (2021)) which was useful to gain video and high-quality audio from the user’s perspective. However, for the purposes of the method a simple pair of safety goggles would also be an effective aid to immersion. The glasses are another prop or proxy for the AR glasses. Wearing them gave participants permission to involve themselves in the task.

Similar to ‘paper prototyping’, the participants are given a number of tasks. These tasks were to help focus the attention on various aspects of the email process. For example, in our test case the tasks were to examine a specifically defined inbox, respond to an email, create a new email, delete an email, add, and remove a calendar event and retain a specific category of emails (work, AR/VR, AI) for later browsing. These tasks involve common activities to give an overview of possible interactions within a complete email system. Participants are also allowed to return to these actions at any time, giving the opportunity to re-invent and re-organize based on subsequent actions. The emphasis of our elicitation process was to facilitate the vision of the users.

3.2 User Study

This case study emerged from a larger project looking at the design of a three-dimensional GUI for AR. We selected email as an application problem which would be familiar to all our participants. This is in line with other productivity based AR research (Li et al., 2019). The ultimate goal was to create a reusable toolbox of tested components for a range of information processing work-based applications. In real systems, users with knowledge of a specific problem domain would be recruited along with a process to define the application area. While the choice of email was largely arbitrary its familiarity permitted wider recruitment of participants.

3.2.1 Participants

We recruited 11 participants (all male) with ages between 18-54 and two stated they had VR experience. We attempted to recruit female participants, but the host institution (university computer science department) had small numbers of women available and therefore might also be a self-selection problem. Recruitment was by posters and email within the institution. Participants were given a £10 Amazon voucher for their time. The study was conducted with two sessions over two days. Five participants attended the first session (P1-5) on Day 1 in Location A and six participants attended the second session (P6-11) on Day 2 in Location B. The location of the experiment had some impact on the layout of the seeded items but not on the methodology.

3.2.2 Ethics

The experiment received ethical approval from the faculty in the standard manner. All information recorded from the participant was maintained with an anonymous identifier for each participant. The data from this experiment was stored in accordance with university data regulations. Participants signed a form to confirm informed consent at the beginning of each session. They were also debriefed at the end of the experiment.

3.2.3 Study Procedure

In this user study, we focused on the improvisational nature of the method and explored the ability for participants to understand what an augmented reality interface entails. We were also interested in if participants could feasibly use the provided materials and setting to develop their own user interactions with the system. Our method begins with some samples we call ‘seeding’. We were curious if participants would use this and be heavily influenced by it.

3.2.4 Materials

The most obvious aspect of the system was the ‘washing line’ (see Figure 1). This was the sample of emails used in the experiment containing a mix of simple one-line text emails, images, and longer emails. The set contained 23 single page emails, 2 two-page emails, 1 four-page email and 1 six-page email. Three of the emails also contained full color images. This gave a cross-section of the variety of different possible types of email that could occur in actual inboxes. The emails were fixed on a washing line as A4 sheets with a Calibri font and text size of 28pt for titles and 11pt for main text. The from and to lines were colored blue and sized 16pt. The participants were about 2m away from the line and were able to read the titles of the email without moving closer but had to move the email closer to read the main body. Emails were presented with their complete length shown, extended downwards. The email template we used for constructing a new email, using a standard layout for an email (to, subject, body) on an A3 sheet, was given to participants upon asking to create a new email (see Figure 2).

A desk was setup in front of participants, with a pointer and keyboard and was located with the washing line behind it (see Figure 1). The use of a pointer was inspired by some VR systems to permit 'touch at a distance'. Many current virtual and augmented reality systems use handheld controllers, and the laser pointer was a physical representation of both these input constraints. For the first few participants (P1-5) a table was set aside for contacts with a set of toilet roll tubes labeled with possible contacts, to the right. The calendar was a fixture of the experiment that evolved as it progressed. After P1 it was altered to highlight the current date of the task, with marker pen, and a large version of the scenario date was added in a box at the bottom of the calendar. Sample meetings on the calendar were already added as post it notes. The position of the calendar changed between participants and the day of the experiment, on Day 1 it was primarily behind the participant, on Day 2 primarily in front. The calendar was behind the first participant of Day 2 (P6). The “storage zone” was suggested to participants as a place to keep emails not on the main line. This was located to the right of the participants on Day 1 and the left of participants on Day 2.

3.2.5 Role

Participants took on the role of someone who must sort through a selection of email for someone else, categorize it, and respond to important selected communications. Other interface possibilities were explored through iteration of the prototype system.

3.2.6 Data Collection

Participants were filmed using Tobii Pro Glasses 2 (2021) and fixed cameras located around them. Their vocal and gestural output was monitored, and their comments on the system and ‘think aloud protocol’ (van Someren et al., 1994) recorded as an important part of the prototyping process. The mock-up was developed and iterated in response to user feedback.

The following data was collected: first person video, third person video and facilitator notes. In total, 11 sessions with the method were enacted over the course of two days, 5 in Location A and 6 in Location B, with 284 minutes (M=26m) of video between them.

These were combined with notes and impressions created by the facilitators. These sessions were transcribed and then subjected to ‘thematic analysis’ (Braun & Clarke, 2012). Once themes were identified they were reviewed, and coding re-applied to the data. Statements were classified using codes recording the responses and actions of participants. New sub-codes were then developed, based on patterns and the re-occurrence of codes within each concept. The results of this analysis are presented below.

We will now present the results of our user study looking at the categories that we identified from the participants, which relate to the performance of the technique. Then a discussion will follow with insights for the design of an augmented reality email application. This is intended both as an output for those who may be designing similar augmented reality systems and to also give an impression of the kind of discoveries that this technique can engender.

4 Results

In this section, we present our analysis of the experimental data. After applying thematic analysis to our collected data, 5 categories were identified as relating to the performance of the prototyping technique: Seeding, Affordance, Originality, Legacy, and Improvisation and Facilitation.

4.1 Seeding

As mentioned in the methodology it was important not to begin with a blank slate, but as with other participatory design experiments we setup a (simulated) basic system based on our ideas of what an augmented reality email system could look like, to give some indications of what was possible to the participants. The following categories relate to elements of seeding.

4.1.1 Accepted

A good example of seeding was the email template and the presentation of the emails. The email template we used for constructing a new email was accepted by all participants without suggestion of modification.

Very few participants mentioned anything about changing the size or shape of the emails or the size of the text. In response to this P1 stated *"This is perfectly fine for the title of the email".* However, P7 and 11 wished to only have the titles displayed in their layouts. This may be due to the flat nature of emails, which would not appear to need any three-dimensional or spatial elements, and the standard layout of email across existing email applications.

Another example was the washing line presentation of documents. Some participants rejected the line of emails horizontally across the visual space (P2,5,7,10), but others accepted the seeded idea (P1,3,4,8).

A further example accepted by P1, was a suggestion by facilitators to add a meeting to the calendar. This suggestion was to push the email with the meeting details directly into the calendar, which would automatically update the event details. *P1 "Yes just push it in"*. P1 was also the only participant to use the contacts table to look up a sender of an email.

4.1.2 Rejected

Most significant were ideas which had been seeded but rejected. For example, the Laser Pointer.

During the introduction, all participants were offered the use of a laser pointer, many decided against its use (P5-P11). P1 used the pointer combined with gestures. P2 and 4 held the pointer through most of the experiment but exclusively used hand gestures, this could be seen as feeling like they needed a controller for tactile feedback but also preferring direct interaction. P3 used a pointer exclusively. Others used gestures and/or voice. P5 and 7 specifically rejected the pointer when asked if they wished to use it. *P7 "I feel like hand gestures would probably be much better … people wouldn't really try and use [a pointer] as much".*

Many other seeds were rejected by participants. *P1 was offered a trash can but instead threw the email on the floor behind them to delete, "Can't I just throw it on the floor?".* Facilitators suggested possibility for vertical stacking to P8, but responded, *"maybe for this horizontal is better … to see things better"*. P11 was offered that the emails could curve around them to be closer, they rejected it saying they preferred them going off into the distance, *P11 "I could also have, this is all real estate for apps to be in. So I can just turn my body to have apps here because all of this is free space. Whereas this is, this is my tools. This is my searching. [This is my inbox]. This is my emails."*

4.1.3 Transferred

Part of the methodology was the ability to iteratively offer interesting or novel ideas from previous participants. This enhances the options and stimulation of the participants who were unsure of what they wanted in their interpretation of the system and see if the ideas would propagate forward.

The first situation when this happened was when P1 suggested that when an email is removed that other emails would move up to fill the gap. *P1 "They've all moved up" "Gap has closed".*

We had not thought of this so subsequently this was asked of following participants if they wanted the same which most did (P2,3,5,7,8,10,11) with an additional animation (P4 and 9 specifically did not want animations to depict actions).

There was also one instance where, while waiting for their turn, a participant (P7) saw the action of a previous participant (P6) and adopted one of their ideas, in this case using a "scrunching up" gesture to delete an email. This was interesting as this was a completely novel means to delete an email that as far as we know is unlike any existing interface, and yet it was adopted by a following user.

4.1.4 Extended

This subcategory relates to participants who took an idea we had seeded for them but expanded its use beyond its original means but retained the same use within the system.

One idea that was taken by some participants and extended was desk controls. Controls were transferred from previous participants, originally as sticky notes on the desk. Most participants took this idea and instead attached the controls to the actual emails instead (P3,6,7,8,10,11). This makes sense as it implicitly encodes the selected email with the functionality, to apply controls to an email, instead of having an email context that the controls are then applied to.

P10 "The way I imagine it is you pick something from the [washing line], so it comes up to you and then besides it … you get all the functionalities you may need for an email"

P11 "Right. Okay, so I've got it down here. … If I was wanting to do some form of like replying to it, … maybe toolbar on this side or toolbar on this side where … I'm picturing, … I brought it out and it's here and it's like, okay, I need to respond to this. Maybe a gesture should like, bring out toolbar on the side."

Email length was depicted by our initial setup as the longer the email the longer the sheet of paper it was displayed on to show the entire length. This was expanded on by many participants. Suggested layouts were to have the email in a box/window and be able to scroll down (P5,6,7,9,10), fade the emails as they get too long to be displayed in view (P3,5) and denote the length with thickness instead of length (P7,9), *P9 "Like a book"*.

P6 changed the emails to be segmented by day on the calendar but when selected would retain the line order but newest right to oldest left instead and closer to the user.

P9 "I would actually have it around me". Then decided they would like a *"physical stack"* of emails on the desk that represents the inbox. *P9 "Makes more sense, in my world, to look down on email". "I don't see email as something where I'm contemplating anything, I see email … as very direct"*. P9 wanted email displayed below them (on the desk) as they *"want to see forwards … to not lose omnipotence"*.

P10 Suggested having email *"in a circle around you"* and browse it by rotating the circle, *"Slide through them until you find what you need"*.

P11 wanted most recent emails on the right and oldest on left. *"More logical as you read from left to right"*. P11 also wanted multiple rows for different folders.

4.1.5 Adapted

This subcategory relates to participants who took a seeded idea and used it for a new or novel context or purpose.

An interesting one was the task given to participants. All participants were given a task brief on arrival, but few actually stayed with that task (most never mentioned it), and we felt it was better to accommodate a generally first person driven narrative that the participants supplied than to force the one given. P1 did not follow the prescribed task and created their own, *P1 "So I've just arrived at work, but I've been checking my emails on the train on the way in ... I've flagged several for follow up".* P6 was the only one to follow the task.

A part of the seeded environment that was not used as we expected was the "storage zone". The storage zone was rejected by P1 in favor of using the desk as a "task in progress" area, *P1 "If I put [emails] up here it will just become another inbox and fill with junk".* Later they suggested using this area as an *"Uncertainty area"* to contain emails that may later need to be referenced by an email returned from someone else. P2 decided to have a floating options menu above the storage zone and have buttons for different folders such as sent items and flagged emails. P3 moved emails into folders spatially arranged in the storage zone, such as Admin and Waiting, to deal with later. P11 wanted application icons to the left to open things such as calendar and contacts.

4.2 Affordance

This category relates to participants using the available extra space offered by the system and the freedom given by the situation to come up with new ideas that would not otherwise be possible.

4.2.1 Blending Reality

Blending refers to elements which merged the virtual with the physical. This suggests that users are comprehending and imagining the augmented reality and its possibilities and utility.

For one participant, P4 wanted to take advantage of the views of the physical world.

P4 "I think it probably depends on, on what the use case is. I would say … if I don't need to kind of see the edges of the document, [then I'll probably want the rest of my periphery], … even if it's just to look out the window at something, I won't want it clogged with this, but it'd be nice to have the ability to expand something … so maybe you could see … more and less, but I think it definitely would like the ability to keep it as a window. So, so the physical world is still there if I want it to be."

Facilitator "Yeah … there's a lot of debate about … technicalities … No augmented reality could actually block anything at the moment. It will tend to be seethrough-ish … yeah, you don't always see the ghost of whatever's in the room behind it."

P4 "Yeah … but I don't just want to see the ghosts. I just want to see it. Nice. Pretty tree out the window."

4.2.2 Spatial

This subcategory refers to the use by participants of the spatial nature of the augmented reality system.

P1 had email on the desk as *“an open issue that needs to be closed”*. P2 wanted to be able to *“pull the email off the screen”* once it was composed and send by throwing. P3 wanted new email to appear at their current location, so it could remain in view of the calendar. P9 wanted to pick up documents and move them between folders (stacks of documents on the desk) by hand and push them off the desk to archive them. P9 also wanted a clock on wall as an example of *“low fidelity” “passive”* objects in the background that could be unconsciously referred to. P11 wanted email displayed at a *“comfortable angle”* just below the eyeline, fixed in space. P4 wanted email to scroll to be triaged more effectively.

P4 “Um, so I'm just browsing my email, so I would probably … maybe flick, flick through them. Um, so [I] haven’t answered these ones that are in front of me from newest first … and then I'd make a gesture for the line to shift.”

(Gestures left to right, hand held out flat).

P4 “Yeah. Some of them thinking that this would scroll. A steady speed so that I could, … read this subject and who it's from. And then I could do that for, there's not too many new ones, so I glance at everything first. And then … maybe decide which to read in more detail”.

4.2.3 Dimensionality

This subcategory identifies elements where participants have responded to the volume and depth of the spatial interface.

A means of having both original and reply emails next to each other for reference was suggested by participants (P1,2,8,11) and usually the desk space was used. This is a feature that is not available in many current email applications. P11 *“And maybe it would be like, maybe not on top, because I would still need to know what the guy was saying, because I always hate when an email's like, I go to one and I have to respond to it, but I don't remember what [was said]. So … having that to like one side, like just not completely in vision, but just there.”*

4.2.4 Embodied and Physically Inspired

This subcategory covers physical elements which impacted on the ideation process.

During the experiment, we specifically introduced the choice of standing (P1,3,4,6-8,10-11) or sitting (P2,5,9) while using the AR system, while standing was the starting position. P2 when asked if they would prefer to stand or sit said they would prefer sitting, *P2 “I think I prefer sitting down as well, because it feels more natural the way I would write an email. I think when I'm standing up, I feel more like I’m in a virtual reality game I don't feel … formal … But then again, some people might want that more interaction, but I think this feels more natural for me.”*

We found it surprising that so many participants wanted to stand as part of the interface. This may be partly due to the embodied nature of the conditions, and it may also be due to the tacit realization that freedom of movement would allow interaction with a wider field of information.

Many participants wanted a virtual keyboard (P1,2,3,5,6,7,10,11) which appeared when needed, via a text field. This is very similar to how a virtual keyboard on a mobile device functions. This is interesting as it also suggests an egocentric view influences where uses want a keyboard to appear, as on a mobile application the keyboard appears below the text box to be interacted with, however in three dimensions we have found people expect the keyboard to appear in front of the user (this is also how virtual keyboards function in virtual reality applications such as Oculus Home and Virtual Desktop).

4.2.5 Limitations

This subcategory relates to participants who were sensitive of the limitations of the technology and user interaction involved in the system design.

Gestures were offered to P1, but they said, *P1 "Even a gesture is too much effort"*. P1 was very against *"large gestures"*, they related to Wii games that used gestures that could be done with less movement as efficiently as with more. *P1 "I might [do] big gestures for the first couple of days … but after a while I will be minimising those movements"*.

P9 had email "billboarded" and fixed to the user's view at a fixed distance (not fixed in space), to avoid perspective issues. P9 *"While I'm composing [email] I want everything billboarded"*, they wanted email flat in view to avoid motion sickness. P9 also suggested altering the text font/size in 3D to be larger than in 2D.

4.3 Originality

This category relates to participants that generated entirely new ideas, unrelated to the seeding and environment provided.

4.3.1 Gestures

Gestures were suggested to participants as a way to interact with the system, with no examples provided by facilitators. Participants generally acted out gestures in combination with a verbal description of what they were doing.

P1 suggested a *“typing gesture”* to call a virtual keyboard. P1, 2 and 11 suggested a grabbing gesture to bring email closer to view. P2 returned an email to the main line from being held by *“throwing it back”*, P7 also threw an email towards contacts to send it. P5 pointed at an email to bring it closer. P6 wanted to *“grab and stretch”* to enlarge web page windows.

P6 “So the browser comes up and then this has got this information again with the same system of the email that would just have like a scroll. But if I wanted to enlarge it or grab it and then stretch it. “

P6 mimes grabbing corners of the window with both hands and pulls outwards.

P6 “Okay. And so sort of like, you know, when you code in one of the boxes in web, and it's got the little corner where you can like drag it out, it would sort of be like that, but you could just sort of yeah. Pull it out.”

P7 grabbed email and dragged it to an archive button on a menu to put in the archive folder. P7 also made a gesture moving their hands towards each other to close the calendar. *P8 "point or tap at email to bring closer", "Wave upwards to put it back in the list".* P9 *"Physically rearrange folders"* by moving emails between stacks by hand. P9 also wanted to *"Drop a match [into bin] and set on fire"* or drop into a shredder to permanently delete emails. P11 wanted a clock icon for time which the hands could be moved with a twist gesture to set the time. P11 also pushed the calendar back onto a tool panel to close and deleted email on the washing line by *"plucking"* it down at distance.

Another interesting observation is that all but one participant (P4) consistently held the emails in a hand to read, they would often take it from the hand of the facilitators (who were simulating a floating document), this may be due to the physicality of the paper or a wish to control the viewing angle in 3D space.

4.3.2 Input Modality

This subcategory relates to conditions where participants suggested alternate input modalities from gestures.

P1 suggested voice search, unprompted, to find an email they needed reference of based on another email. Voice to search the emails and other parts of the system were suggested by a further 4 participants (P2,4,6,11). Voice was also used by a few participants for dictation, which was suggested by them (P2,8,11). P4 wanted voice commands for most the functions within their design and also suggested eye tracking and keyboard shortcuts (tab) to select email fields.

4.4 Legacy

This subcategory relates to participants who used layouts, conventions or interactions that presently exist in email applications or existing technology such as desktop computers or mobile smart phones.

4.4.1 Arrangement

The arrangement of the documents, originally on a washing line, was one of the major parts of the setup to be modified by participants to fit a more legacy feel. All arrangements, other than the original washing line, were suggested by the participants. The potential interfaces were produced to the participant's requests using available materials and facilitator acting out of functionality, for participants to fully conceptualize their ideas.

P1 decided to have a similar layout to Gmail which has a list of buttons for Inbox, Sent, Deleted, etc. which can be clicked to return to the given state. P2 decided to have a persistent screen and desk as their main workspace area as with a desktop computer, *P2 "Virtual desk space … with multiple monitors [for] different purposes",* such as displaying emails and web search*, P2 "I want it to be like a normal browser".* P5 suggested ordering vertically *"like an old-style roller blackboard"* with new email at the bottom. P6 wanted *"Standard computing conventions but touching it instead of clicking it".* P7 wanted the emails to be vertical *"like Gmail".* P10 also preferred emails to be vertical *"like Gmail and Outlook"*. P11 wanted an interface to the side of the calendar day screen with an *"Outlook"* style dialog box.

P9 wanted to have all email textual interaction to be managed in a 2D *"billboard". P9 "Doesn't make sense to have anything but a 2D canvas"*. They used a *"real mouse"* to select text in email to edit and wanted to see a *"carrot"* (2D cursor) on the email billboard as is found in a desktop email application. P9 also wanted to scroll canvases with a mouse wheel within a fixed window size and have minimal difference in the editing mode to a desktop email application, with Outlook style email interactions at the top of email. They also mentioned automatically adding an event to the calendar if date was clicked in an email, *P9 "like iPhone"* (iOS).

4.4.2 Gestures

Gestures were also influenced by mobile email applications.

P1 used a *"tap"* gesture to select the input fields when creating an email, this is very similar to how it would be done in a mobile email application, used by most participants (P1,6,7,8,10). P5 used directional swiping gestures for interaction. *P5 "This is how I archive things normally with my mobile app".* P6 scrolled and tapped with a hand to select a contact from the list. P10 clicked on or slid up or down to open email and swiped email down or to the right to delete it. P10 slid email left to archive it and slid left and hold to open a list of *“categories”* to put the email in, with a new category option.

P4 used a *“Wave away … Minority Report style”* (swipe) gesture to remove a window. This was the only instance of a non-existent legacy interface influencing a participant’s design.

Participants (P1,2,4,5,11) wanted screens to be minimized or removed by swiping down, this is similar to mobile task managers.

4.5 Improvisation and Facilitation

This subcategory relates to situations where the improvisation aspects of the design procedure helped participants come up with novel ideas.

4.5.1 Clarification

This subcategory relates to instances where participants used improvisation as a means to clarify the context of an action.

Facilitators suggested clicking on a button to summon a virtual keyboard to P1 which was improvised, *P1 “How did I do this?”.* P1 then decided on their own method of a *“typing gesture”*, miming typing in mid-air.

P1 after acting out the motion of pushing email into calendar, deliberated on how to handle an existing event that was being rescheduled, *“just thinking what I wanna do”*, they then pushed the email into the calendar to add an event and removed the old meeting by pulling off the sticky note.

P2 was not sure if they could throw an email to send it but having it acted out made them more confident. They also kept rearranging the controls on the desk to try and find an arrangement they preferred.

P3 acted out a typing gesture in mid-air (like P1) and facilitators brought a keyboard to them, which allowed them to clarify use of a virtual keyboard.

Most participants at some point would describe an action and facilitators would act it out, which allowed them to clarify if what the facilitators thought they meant was actually what they meant or not, *P10 "Yes, something like that"*.

4.5.2 Artifacts

A major artefact within our email application was the calendar. We added this to see how participants would interact with dates in emails, but the calendar was heavily used throughout by all participants in a variety of different ways [P2,3,6,7,8,9,10,11].

P2 wanted a calendar in a window. P6 wanted all the emails to be contained within the calendar (see Figure 3). P7 clicked on a date in an email and said it would "bring up calendar icon". P11 had the calendar not open until the application icon was selected. P10 wanted automatic detection of dates in an email that would allow the calendar to open contextually.

P10 "I would maybe have one of the functionalities on the side and probably have an AI detector [for] dates in the text, so it can [be] automatically … highlighted and then you have an option to automatically add that to your calendar and from there, you actually set up everything in detail."

5 Discussion

The results were divided into categories and subcategories using thematic analysis to relate themes across the data from all participants. This analysis identified 5 categories Seeding, Affordance, Originality, Legacy and Improvisation and Facilitation. For this discussion, these categories will be further combined, and cross referenced into the following 3 categories of Seeding, Affordance and Gestures. Following this implications for elicitation and design will be given for designers who are looking to prototype future AR projects.

5.1 Seeding

For the seeding of participants, the worry was that they would be biased towards the starting setup of the "washing line" display and other seeded elements. However, this was not the case as many participants modified or completely altered how they wished the documents to be displayed, how other elements were displayed or added completely new elements to their interface (such as web browsers). As well as this two of the main seeded ideas, the laser pointer and contacts table, were almost universally rejected by participants. This suggests that participants were not overly biased by the starting setup and were able to use it as a means to start creating ideas in the space, without needing specialist design knowledge or skills.

From this perspective, it appeared that the initial seeding and the context, of being within an imaginary augmented reality dealing with electronic mail, was enough to help scaffold ideation. The process of carrying over ideas from previous participants, when the current participant was clearly unsure, created interest in areas for transference, extension, and adaptation. All of which seem to suggest that participants found the existence of previous concepts stimulating. Yet this does not seem a limit to truly original ideas, such as P2 pulling the email off the screen and other ideas afforded by the nature of the system.

5.2 Affordance

The affordance given by the augmented reality system was utilized in many different ways by participants. Participants were also able to imagine how they could use the space provided by the environment to have added benefits over traditional desktop GUI. They were able to physically place documents, virtual objects, and interface elements as they wished and in doing so were able to comprehend that they could use this added dimension of spatial freedom to their advantage. Affordances such as the ability to have multiple emails present to reference during email composition or the ability to have multiple browser windows available and locatable in space were ideas put forth by participants, without facilitator's having to explain how this would work or the technicalities involved. They also were able to comprehend the nature of an augmented reality interface, in that it does not obscure the world around the user, enabling elements of the environment to be used or accessed at the same time and in the same space as the virtual environment. Participants who had previously used VR but not AR could still understand this naturally with the informance aspects of the method.

All the interfaces produced by this method are focused on spatially locating the elements of the interface within the surrounding environment. Interactions with the physical environment are more in the ability to spatially locate surrounding interface elements (Spatial AR) rather than interacting with physical objects in the environment (Tangible/Overlay AR), though this also occurred in some of the sessions (such as with physical keyboards). This is also possible in a VR application but does not offer the same spatial and body cues as are available when the surrounding environment and actual body of the participant are also visible.

5.3 Gestures

Gestures were a big part of the interfaces designed by participants, this is unusual in existing interfaces, so this suggests that the nature of augmented reality lends itself to gestural input. This is consistent with the current technological push in AR/VR headsets to use hand tracking (such as the HoloLens 2 (2021) and Oculus Quest 2 (2021)). It is possible that participants have been previously influenced by these technologies, but our sample had a very low number (2) with previous VR experience, suggesting this is not the case. Gestural input was also not particularly suggested as a means to interact with the system by facilitators, it was given only as an example along with pointer input and voice. Most participants used some form of gesture in their designs, and many seemed to be influenced by legacy input technology, primarily smartphone touchscreens. There were however participants who created completely original gestures to interact with, such as throwing an email to send or delete, this shows an ability for the method to remove inhibitions of participants from feeling they must conform to previous design paradigms such as GUI or WIMP. Participants were also very keen to combine what would be considered separate applications such as email, calendar, and web browser as a single interoperable system with aspects spatially located in the augmented environment. This suggests a desire to break from the separated nature of traditional desktop apps and instead have something more akin to a paper notepad, which does not ascribe a purpose other than to be written on but can be used for many different purposes.

5.4 Implications for Elicitation

From an interaction design perspective, we discovered that the process of enacting the method certainly pushed us far away from our conceptions of what an augmented reality email prototype might include. For example, users wanted controls which appeared around the element being modified. This makes a huge amount of sense in an augmented environment, where a user's attention could be far away from any inspector or virtual menus.

As with all elicitation processes there are potentially a divergence of ideas, along with areas of commonality. As always, it would be up to the interaction designer to impose order and consistency along with an implementable system onto the speculations generated from user input.

This and the above elements suggest that the method was successful in eliciting a high-level idea of how the user interface might operate, for participants who had little or no prior experience, while using a very low fidelity model in terms of material requirements.

5.5 Implications for Design

In this section we will outline some of the more significant insights for the specific test case of augmented reality email and summarize elements mentioned in the categories above. It was clear that many participants would prefer to stand, possibly to allow them to reach into a greater volume of data. An AR system should certainly consider the ability to operate in both standing and sitting modes. Handheld pointing devices also were rejected for more fluid unencumbered hand and gesture tracking. The use of simple voice commands ("new mail", "reply") and gestures seem to be a natural mode of operation. However, our participants seem to expect dialog boxes, as are familiar in traditional GUI, for input when the machine needed more information from a user.

Incoming email should certainly be laid out physically in space (rather than attached to the user's location) although the configuration between washing line and alternatives like circular carousel or vertical stacking was not in strong agreement. Gestures such as drop-to-delete and potentially throw-to-send, particularly if they do not require large movements, seemed to be a natural expectation.

Users took advantage of the extra space an augmented reality system could offer, and they expected to be able to use this in a kind of email triage mode. This would involve being able to place emails in a location of significance for future reference, prioritize emails and save email for later. All participants expect to strongly merge email with a calendar application for scheduling. With the calendar either being the focus of the application or clearly present within it. Users expected natural language parsing to identify times and dates within emails to allow for easy integration with the calendar. Users also expected hyperlinks within emails to be interactable from within the email application and have close integration with a web browser spatially located within the same interface. Controls should be attached to the object in question, and it was expected that a virtual keyboard would be used for text entry. Finally, email was expected to be integrated with other platforms such as mobile.

5.6 Limitations

The limitations of the method are in the specificity of the intended case. We were focused on head-mounted augmented reality and while it may be applicable to other forms of head-mounted devices such as virtual reality, and possibly to other forms of augmented reality such as mobile and projector, we have not evaluated if this is the case. However, we are confident that this method could successfully be applied to different use cases of spatial embodied augmented reality interface design. In this experiment we also had problems recruiting women to take part. This should be remedied in future experiments.

A further limitation could be in trying to apply the method to later stages of design fidelity. We intended it specifically for early design stages as a means to elicit user input and generate routes for design, so it is unlikely to apply well as an evaluation method for later stage more concrete designs.

5.7 Future Work

There were many avenues for future research generated during the course of the test study. Any of the co-designed systems could be reproduced in higher fidelity and evaluated for viability. A combination of popular components from each design could be generated and evaluated. User generated gestures could be taken from the video and shown to others to see if they agree with the usage. Individual points of interest could be explored such as standing vs sitting to see if this is a feature of spatial interfaces or just of our design layout, gestures could be compared to pointer input to determine if the current trend towards pointer ray casting over direct interaction was correct, and user spatial layouts could be evaluated to see which work best in practice. The method itself could be further developed on to refine what works best in different design cases and could be applied to additional spatial or head-mounted interface design cases. It may also be worth exploring a session with a group of participants to exploit the organic seeding opportunities.

6 Conclusion

In this paper, we proposed a new participatory design method for spatial embodied augmented reality based on 'informance design' called 'spatial informance design' and explore its use in augmented reality.

We found the method to be a fast and very lightweight way to ideate an application with real potential users. Given the variety of designs produced during our test study we found it a rich source for design. Many different ideas can be trialed during a session, and between sessions, providing a variety of routes that can be taken further by AR designers. The analysis of the data is consuming but it pushes the designers to focus on a user centric approach avoiding many early pitfalls. The old adage, that when your only limit is the users' imagination then you are pretty limited, is particularly true in the field of AR. We found that with seeding, participants were free to speculate about an interface they had never seen the like of before. These responses were both rich and diverse, yet showed areas of consistency, and pointed in directions which were compatible with future technology without any actual implementation. They also challenged the design to be aware that AR interfaces should exist in an ecological context with other technologies.

We were pleased to see the participants took advantage of the potential that augmented reality had to offer and feel this was a key milestone any elicitation process should have for AR. The elicitation process using real spaces, improvisation, and facilitators dancing email away into the distance, provided an open and positive space. This allowed users to imagine and communicate while focusing in on the task, creating a kind of immersive sketch book.

This light weight process could then be used to feed into more realistic prototyping methods which have been previously published (MacIntyre et al., 2004). In doing so, we hope to avoid long-term downsides of path dependency. Overall, ‘spatial informace design’ created a rapid system which could be used early on in the design process to imagine spatial interfaces which have minimal prior precedent.

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Figure Captions

Figure 1. Experimental layout showing a desk, equipment and the 'washing line display'.

[One Column Width]

Figure 2. Hand with laser pointer and desk with sticky note controls, keyboard, printed emails, and email template. This is shown from the participant's perspective as recorded by Tobii Pro Glasses 2.

[Two Column Width]

Figure 3. This image shows the process of improvising a participant's ideas. In this case P6 was instructing that the calendar would be the main focus of their arrangement.

[Two Column Width]

Figure 1

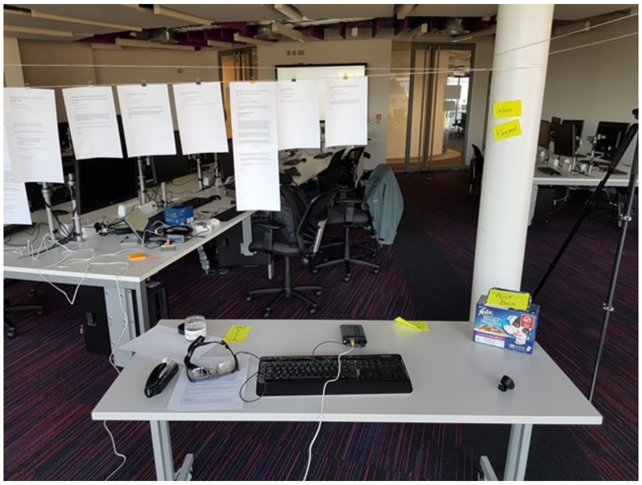

Figure 2

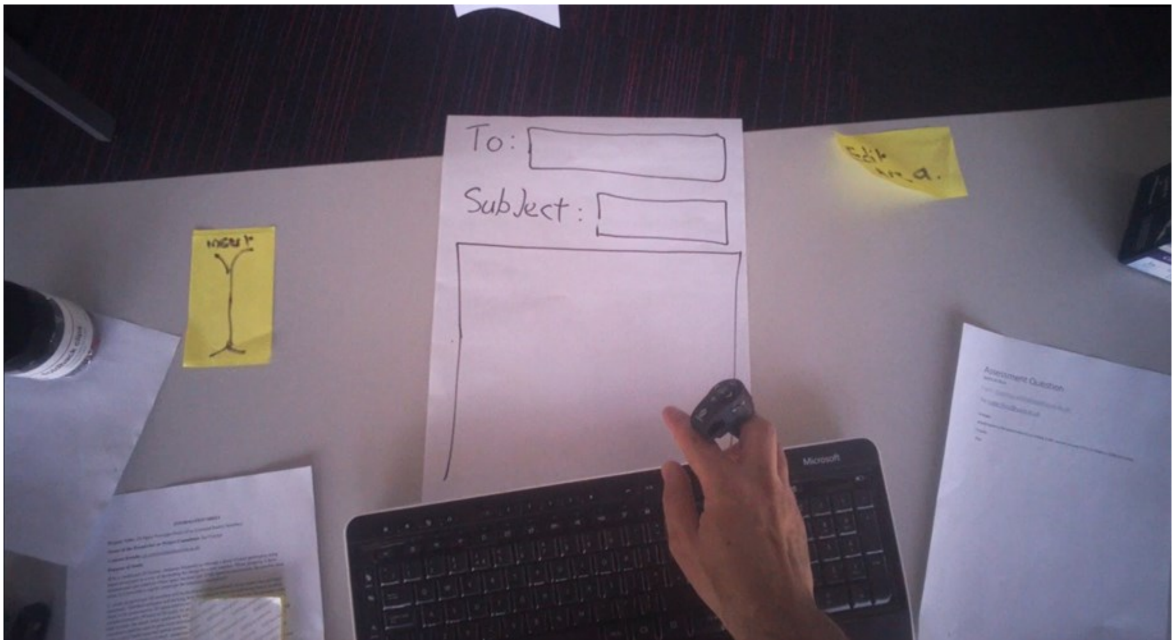

Figure 3