

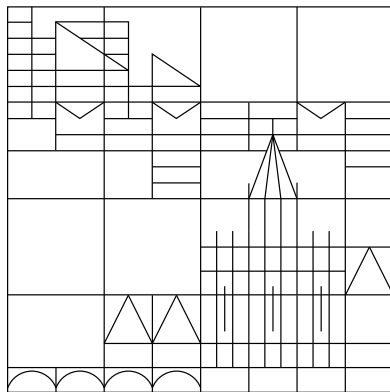
Distributed Digital Desk: Studying the Effects and Influences of Ubiquitous Instrumental Interaction upon Creative Sensemaking

Master's Thesis for the degree
Master of Science (M.Sc.)

by

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Abstract

Distributed User Interfaces (DUIs) place different parts of applications across different dimensions. Research has been concerned on developing frameworks to achieve DUIs. Ubiquitous Instrumental Interaction (UII) is one of the models that has been created to do so. It is based on Instrumental Interaction and it stipulates the creation of applications out of categorized components, documents and instruments. Other models have been extensively evaluated, however, UII still lacks in-depth studies from users' perspective.

This thesis seeks to make a first step into filling this gap. The Distributed Digital Desk (DDD) is a system that enables the creation of applications with DUIs. It provides several instruments that can be combined with documents to perform creative sensemaking work. These components can be placed in any kind of device that can open web pages. Hence, users can combine mobile phones into their own distributed application.

An explorative within-subject study was designed to better understand the influences of UII upon creative sensemaking. Participants used three applications to perform creative sensemaking tasks. All applications contained a document, while the interface to create and edit content in this document changed. The first one offered a toolbar with settings, much like classical WIMP related interfaces. The other two were made up of instruments. In one, the instruments were all in the same surface as the document, while in the other one they were in individual physical devices. This study showed that participants changed their behavior when presented with applications based on UII. They switched from mainly focusing on the objects they were interacting with, to focusing on the actions they were performing.

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And finally, a million thanks to my grandparents. Without you I would not be where I am today. Thank you for always being there for me, even when there is an ocean separating us.

Declaration of Originality

I hereby affirm that I have independently written the attached Master's thesis on the topic:

**Distributed Digital Desk:
Studying the Effects and Influences of Ubiquitous Instrumental
Interaction upon Creative Sensemaking**

and have not used any other aids or sources other than those I have indicated. For parts that use the wording or meaning coming from other works (including the Internet and other electronic text and data collections), I have identified them in each case by reference to source or the secondary literature.

Furthermore, I hereby affirm that the above mentioned work has not been otherwise submitted as a thesis for a Master's. I further understand the pending completion of the review process I must keep the materials available that can prove this work was written independently.

After the examination process has been completed, the work will be submitted to the Library of the University of Konstanz and catalogued. It will thus be available to the public through viewing and lending. The described data given, such as author, title, etc. are publicly available and may be used by third parties (for example, search engine providers or database operators).

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Konstanz, October 20, 2016

Carmela Acevedo

Conventions

The author of this thesis uses the plural personal pronoun “we” throughout this document, even for work done solely by her.

The Harvard citation style is used throughout this thesis to refer to research papers. Footnotes are used for web resources.

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Chapter 1

Introduction

Applications are everywhere. They offer a bundle of functions that combined allow users to achieve a goal. Browsers enable surfing the web while word processors deal with text. Smart phone applications, or apps for short, have become ever more ubiquitous. They offer diverse but specific functionality. Already in 2010, Apple trademarked the slogan “There’s an app for that”¹. There is always an app for whatever unique need the user has. In 2013 the measurement company Nielsen analyzed app usage across approximately 5000 users². They found that users spent their time between more than 20 different apps a month.

Even though there are so many applications, these are very isolated. Most of them offer limited, specific, and hard to combine functionality. If a user edits pictures in Instagram³, but wants to include one in a presentation in Google Docs⁴, she might run into trouble. The process involves exporting the picture into the right format to upload it somewhere else. What if she decides that she wants to change something in the image later on? The image has to be re-exported and uploaded. These problems occur because applications are usually incompatible isolated units. This fragmentation is not only present in desktop and mobile applications but also has reached the Internet.

Even though, or maybe because, the Internet offers quick access to diverse sites, it also converged into an application based ecology. The populariza-

¹Apple Trademark List - <http://www.apple.com/legal/intellectual-property/trademark/appletmlist.html> - Visited October 11, 2016

²Smartphones: So many apps, so much time - <http://www.nielsen.com/us/en/insights/news/2014/smartphones-so-many-apps--so-much-time.html> - Visited October 11, 2016

³Instagram - <https://www.instagram.com/> - Visited July 26, 2016

⁴Google Docs - <https://docs.google.com> - Visited October 11, 2016

tion of the Internet and the term “web application” have gone hand in hand. Web applications, much like other types of previously mentioned applications, are programs with a certain purpose. The advantage of these is that they can be used on any device, allowing for more fluid interactions. Ideally, if worked is synced, users can start creating a document on one device and continue editing it with another one later on.

Several companies have made mobile and web versions of their popular desktop applications available. For example, Microsoft Office⁵ is now available as Office Online⁶, a version that works in the browser, and as mobile apps⁷. These companies advertise for mobility and fluid working experiences across several devices. Apple promotes its “handoff” feature⁸ that allows users to start an activity on one device and “hand it off” to another one via Bluetooth to continue working on this new device. However, it is hardly ever possible for users to use devices in conjunction.

The most common interaction of such type is using a mobile phone as a remote control. Users can control the Spotify music playing on a computer by using the Spotify app on their phone⁹. Users can also connect diverse gadgets, like the Chromecast and the Amazon Fire TV¹⁰, onto their TVs to allow their phones to control the content in the TV. These interactions are still entering the market in the user space, yet the study of Distributed User Interfaces (DUIs) has been a popular research topic for years (Chapter 3).

A DUI is an interface with components distributed across several devices that work together as one. This can allow users to take advantage of all devices they own, together with their varied input modalities. It also lets them configure and set them up in space as they please. Thus, DUIs can be very powerful and personalized interfaces. Moreover, they can help users overcome the barriers put in place by applications.

Researchers have dealt with the design and technical aspects of distributing

⁵Microsoft - Office - <https://www.office.com/> - Visited October 11, 2016

⁶Microsoft - Office Online - <https://products.office.com/en-us/office-online/documents-spreadsheets-presentations-office-online> - Visited October 11, 2016

⁷Microsoft - Made to Move - <https://products.office.com/en-us/made-to-move> - Visited October 11, 2016

⁸Apple - Use Continuity to connect your Mac, iPhone, iPad, iPod touch, and Apple Watch - <https://support.apple.com/en-us/HT204681> - Visited October 14, 2016

⁹Spotify - Connect for Computers - <https://news.spotify.com/us/2014/11/07/connect-for-computers/> - Visited October 11, 2016

¹⁰Amazon - Fire TV - <https://www.amazon.com/b/?ie=UTF8&node=8521791011> - Visited October 11, 2016

a user interface in depth. In this thesis, we are interested in the distribution of user interfaces via the use of Instrumental Interaction (Beaudouin-Lafon, 2000). This model focuses on documents and instruments. Documents contain the information users are interested in. Users can interact with these documents through instruments. Ubiquitous Instrumental Interaction (Klok-mose and Beaudouin-Lafon, 2009) builds applications from components that belong to these two categories. These components can then, in turn, be distributed across separate devices. These concepts are further explained in Chapter 2.

In Chapter 3, we explore different frameworks and projects that implement these and other theories. With this, we establish a common understanding of the work being done in this research area. Scientists have explored many ways of distributing user interfaces and their technical implications. They also have investigated isolated interaction techniques in distributed environments. However, to the best of our knowledge, little research has been done towards better understanding the implications that these interfaces have onto users and the work they do.

To tackle this question, we created three different applications with varying levels of distribution, explained in Chapter 4. With these, we conducted a study which is explained in detail, together with the results and their discussion, in Chapter 5. We conclude this thesis with Chapter 6. There, we use the results we obtained in our study to propose future work that could answer new interesting questions that rose from our analysis.

Chapter 2

Theoretical Foundations

The main theoretical model we focus on in this thesis is Instrumental Interaction (Beaudouin-Lafon, 2000). This interaction model views actions of users on objects as mediated through instruments, a concept rooted in Activity Theory (Bødker, 1989). Activity Theory is a conceptual framework that dives into understanding activities as its main study unit. This framework was integrated by Beaudouin-Lafon into the Instrumental Interaction model. Furthermore, Instrumental Interaction was used as the backbone of the Ubiquitous Instrumental Interaction (UII) model and the Views, Instruments, Governors, and Objects (VIGO) architectural model (Klokmoose and Beaudouin-Lafon, 2009). We use these models as the underlying frameworks for studying Distributed User Interfaces (DUIs). Specifically, we want to understand the effects and influences of UII interfaces on creative sensemaking. We use Activity Theory and Instrumental Interaction to guide parts of our analytical process in Section 5.4.

In this chapter, we give a brief summary of these theoretical concepts. Even though a lot of work has been done in the area of DUIs, a gap still exists in the literature regarding the creation and evaluation of an interface based on UII. For example, the application of other theories like Blended Interaction (Jetter et al., 2014), Reality-Based Interactions (Jacob et al., 2008), and Distributed Cognition (Hollan et al., 2000) have been evaluated in the past (Christou et al., 2009). However, to the best of our knowledge, no user studies have been conducted on DUIs that implement the UII model. Therefore, we find it is important to place the development of our study and evaluation inside the frame of Activity Theory and UII.

2.1 Activity Theory

Activity Theory studies the activities humans perform as being mediated by artifacts. Such an activity can be painting a wall, for example. This activity can be broken down into three levels: activity, action, and operation. The overall activity can be achieved via actions, like gathering of the necessary materials or the actual physical action of painting the wall. The performance of these actions trigger operations, like brush strokes or dipping the brush inside a paint bucket. Actions are performed with a certain goal in mind, while the operations are of a sub-conscious, more mechanical, nature.

In this example, several artifacts can be identified, a brush, a paint bucket, and maybe a ladder to reach higher areas. These artifacts co-exist with each other and people can use them because they have a previous understanding of what they do.

These concepts also apply to Human Computer Interaction (HCI). Here, users get involved in activities that are mediated by computer artifacts. A child may decide to draw an invitation card for her birthday. She may need similar artifacts as the aforementioned wall painter, in this case digital artifacts.

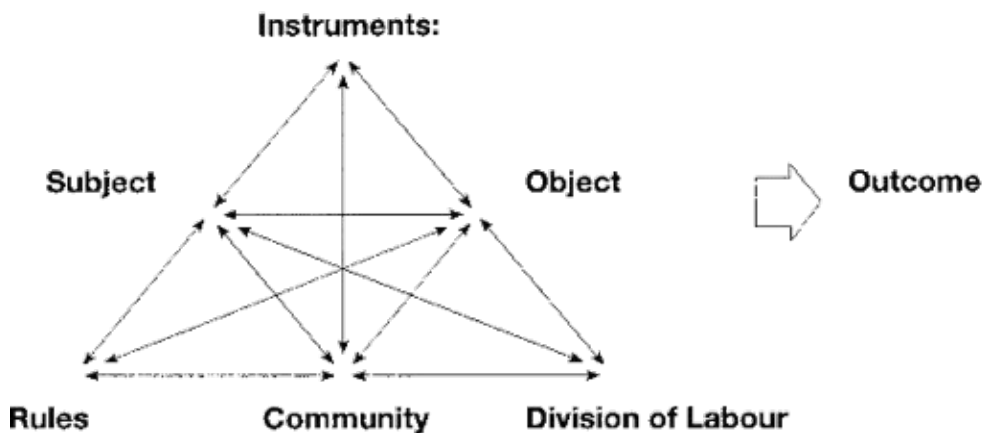


Figure 2.1: Engestrom's Activity Theory network. (Adapted from (Engestrom, 2000)).

Activity Theory is also concerned with better understanding learning (Bødker and Petersen, 2001). When learning how to use a program, the child might have performed brush strokes as an action, consciously and with a specific goal in mind. However, when she gains expertise, this action is turned into

an operation that she can achieve without much thought. If she now uses another program, one with artifacts she is not familiar with, she might run into problems. These problems are called breakdowns in Activity Theory. These breakdowns can lead to her having to step back to understand the source issues. When this happens, she may have to switch from performing an operation back to performing an action. This action is related to understanding or exploring how this artifact functions and, hopefully, leads to her learning something new.

Activities are part of a more complex, shifting network (Fig. 2.1). An artifact can become the object of an action because of a breakdown or because it is being changed via another artifact, like a pencil being sharpened by a pencil sharpener. Subjects bring assumptions they have learned from previous experiences or social influences. These assumptions influence the operations they perform and their choices.

In our analysis we will use Activity Theory to better understand the rise of problems users encounter while using different applications. The top part of the Activity Theory network, subject, artifacts, and objects, can also be considered the precursor to Instrumental Interaction. In the next section we elaborate on this model.

2.2 Instrumental Interaction

Instrumental Interaction's building blocks are documents (objects) and instruments (artifacts). Users turn to computers to interact with information stored in them in the form of documents. As information is the focus of users' attention, documents are the focus of activities. Documents are the objects of interest in this configuration.

These objects can be interacted with, through instruments. Instruments are the reification of actions. They turn actions into objects that users can interact through and with. Instruments are composed of a digital and a physical part (Fig. 2.2). The digital (or logical) part of an instrument may be visibly present in the UI and is the way the instrument interacts with the data. The physical part is the object that users can touch and physically interact with. It controls the logical part of the instrument.

Instrumental Interaction can be viewed as the result of using Activity Theory to frame the way we interact with the physical world and afterwards applying this new view to the digital world. There are two phenomena that emerge from this view that are of special interest to us. Instruments are

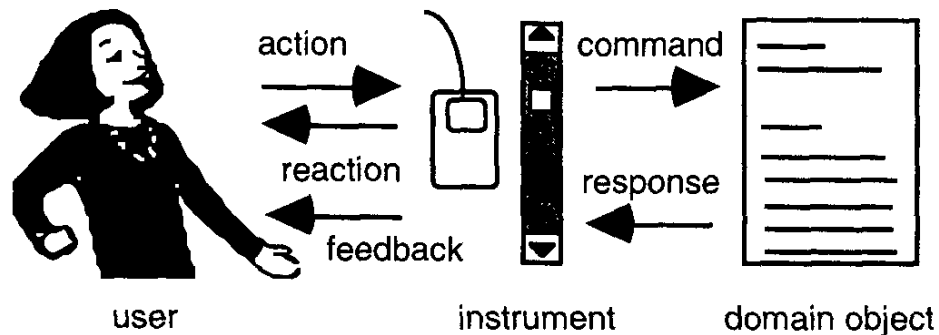


Figure 2.2: Users directly interact with physical instruments which in turn control digital instruments that change features of objects of interest in the Instrumental Interaction model. Source: (Beaudouin-Lafon, 2000).

objects and their actions are unlimited.

Instruments are objects:

We are not used to instruments or tools being the object of an action in common commercial products. However, this happens very often in the physical world. We can use a pencil sharpener to sharpen a pencil, which in turn is an instrument itself. This action changes the pencil from drawing thick lines to drawing thin, refined ones. Or, we can create unexpected mixtures as well. If we clumsily break our pencil in half, we can use some glue to fix it. Nowadays we could even print our own ruler. In the digital world this is seldom possible. Some advanced programs allow us to change characteristics of certain instruments, like brushes or paint buckets. However, most functionality is predefined and immutable.

Instruments' actions are unlimited::

Functionality is not only predefined, but it is also usually very limited. It is hard to imagine otherwise, since digital tools have very specific purposes inside applications. Nevertheless, this is not the case in the physical world. A pen does not only have the ability of drawing on paper, but it can draw on almost any surface. Sometimes this feature may be an inconvenience, if we draw on a shirt. However, if we want to hang a painting in a specific position, we may use this feature to our advantage. In this way, we can use an instrument that has been designed with a functionality in mind to do something else. For example, using a heavy object as a hammer.

As we have seen here, a system designed around the Instrumental Interaction concepts could offer a great amount of flexibility and power to the user. In this thesis, we are interested to see how these two factors, instruments being objects and their actions being unlimited, would influence the way users create and edit content in sensemaking tasks.

The flexibility that Instrumental Interaction offers lends itself to be a suitable model for distributing a user interface. We first formally define what a Distributed User Interface (DUI) is, to later introduce Ubiquitous Instrumental Interaction (UII), a model for distributing user interfaces based on Instrumental Interaction.

2.3 Distributed User Interfaces

Weiser's seminal paper on Ubiquitous Computing introduces a view where all computers, visible and invisible, are interconnected (Weiser, 1991). In this paper he mentions:

“Computer window systems are often said to be based on the desktop metaphor—but who would ever use a desk whose surface area is only 9” by 11”?”

Pads, in contrast, use a real desk. Spread many electronic pads around on the desk, just as you spread out papers.”

Smaller pad devices, like mobile phones and tablets, have become the norm. Even though users currently own several of these (Dearman and Pierce, 2008), most of the time they do not communicate with each other. Few applications, like Spotify¹ and Google Maps², make it possible to coordinate and mirror functionality across different computers. An interface can be distributed by decomposing it into smaller components and placing them into individual devices, achieving a Distributed User Interface (DUI) (Elmqvist, 2011). This type of interface may be desirable because devices can be arranged in physical space, taking advantage of users' spatial awareness (Hollan et al., 2000).

Different types of devices, with different input capabilities like touch or voice, can be grouped together to offer richer multi-modal interactions. A laptop can be paired up with a touch device, like a smart phone, in order to

¹Play Spotify on other devices - https://support.spotify.com/us/using_spotify/play_on_stereo_tv_car/play-spotify-on-other-devices/ - Visited August 7, 2016

²Google Maps Help - <https://support.google.com/maps/answer/6081481?hl=en> - Visited August 7, 2016

augment the possible input modalities of an application.

Elmqvist formally defined a Distributed User Interface as: "...a user interface whose components are distributed across one or more of the dimensions input, output, platform, space, and time."

These dimensions are defined as:

- **Input:** The input capabilities of an interface, these can belong to one or more devices.
- **Output:** The output capabilities of an interface, displays, for example. These can belong to one or more devices.
- **Platform:** Where the interface is executed. This can be done on one or several devices.
- **Space:** The physical space the interface occupies. This can be in one location (co-located) or distributed (remote interactive spaces).
- **Time:** The time in which the communication across components is done. May be synchronous or asynchronous.

This definition does not focus on collaborative interfaces, it is assumed only one user is involved. This is suitable for the analysis we will do in this thesis. The interfaces we will focus on will involve the distribution of input and output across several co-located devices, while the platform is centralized and all actions are synchronous.

Now that we have defined what a DUI is, we can explore how to achieve one through the use of Instrumental Interaction.

2.4 Ubiquitous Instrumental Interaction

Ubiquitous Instrumental Interaction (UII) is a theoretical framework targeted towards the creation of multi-surface applications (Klokrose and Beaudouin-Lafon, 2009). It is an extension of Instrumental Interaction. UII distributes applications via their deconstruction. This is achieved by creating components based on the ideas of Instrumental Interaction, focusing on documents and instruments. Later, these components are combined to create applications. This approach has the advantage of distributing application components across various devices effortlessly. With this framework, Instrumental Interaction is used to achieve DUIs meaningfully.

The creators of this model put it into practice by creating an architecture framework based on it and performing a qualitative evaluation of it. Later on, they developed several applications based on this architecture and also evaluated them qualitatively. In the next chapter we will explain in detail how they did this and survey other work done in this domain.

Chapter 3

Related Work

In the previous chapter we described how Ubiquitous Instrumental Interaction (UII) is a suitable framework to distribute a user interface. There has been abundant research about Distributed User Interfaces (DUIs). Most of it focuses on the technical aspects of achieving distribution. Some of it investigates these interfaces from the users' point of view. However, there has been little research done about UII from users' perspective. With this thesis, we attempt to fill in this gap by understanding UII's influence on users' behavior patterns in creative sensemaking.

The Digital Desk project was a first step towards achieving cross-media interaction (Wellner, 1991). It projected digital artifacts onto a desk surface and tracked interactions with a camera (Fig. 3.1). A blend between the physical and the digital worlds was reached by using image processing to parse physical interactions.

This was the precursor to a lot of work still being done today, decades afterwards (Houben et al., 2014; Hartmann et al., 2010; Gebhardt et al., 2014). Several DUIs use the same approach of a physical and digital blend, while others focus only on digital artifacts (Hartmann et al., 2009). Here, we focus first and foremost on distribution of interfaces among digital artifacts (Rädle et al., 2014).

For such a DUI it is crucial to get the distribution of the components right. As such, numerous projects have studied the technical aspects of distributing a user interface (Demeure et al., 2008; Blouin and Beaudoux, 2010). In this chapter, we give a short overview of the relevant work done in this area to provide a foundation for further analysis.

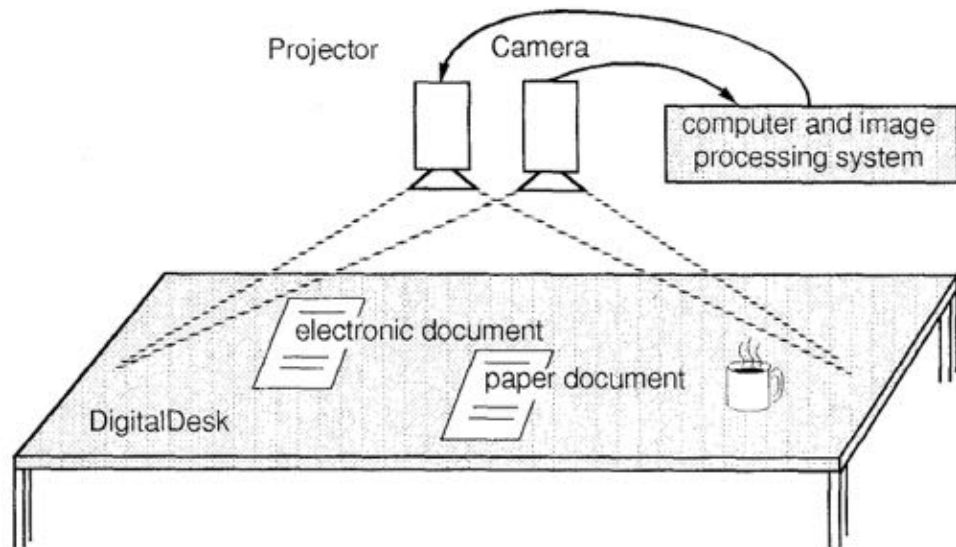


Figure 3.1: The Digital Desk augments an existing desk with a projector. Users can interact with projections and real artifacts. The interactions are recorded and tracked by a camera powered by a server that uses image processing to detect objects and interactions. Source: (Wellner, 1991)

3.1 Frameworks

Demeure et al. introduced “The 4C Reference Model for Distributed User Interfaces” (Demeure et al., 2008). They defined the 4 dimensions of a DUI as: computation, communication, coordination, and configuration. *Computation* corresponds to the elements that are to be distributed. *Communication* corresponds to the time at which the components are distributed, whether it is when the interface is designed or when it is used. The *coordination* is made up of components involved in distributing and controlling the interface. The *configuration* is concerned with the location of components and how they are adapted, or not, to the device containing them. Such a framework is very valuable when designing a DUI but does not offer insights into how the distribution of components influences users’ experience.

Malai is “a model-based user interface development environment” (Blouin and Beaudoux, 2010). It uses Instrumental Interaction to create modular interfaces. Even though it is not directly involved in the distribution of interfaces, Blouin and Beaudoux focus on modularity as a means of adapting interfaces. They evaluated the difficulty of adapting an interface developed for a desktop environment into a mobile environment. They developed and

adapted a graphics editor with both Java Swing¹, an MVC based development platform, and Malai. Time needed with Malai was lower in both the development and adaptation of the interface. This indicated how Instrumental Interaction provides a suitable framework for the separation of reusable components at development time.

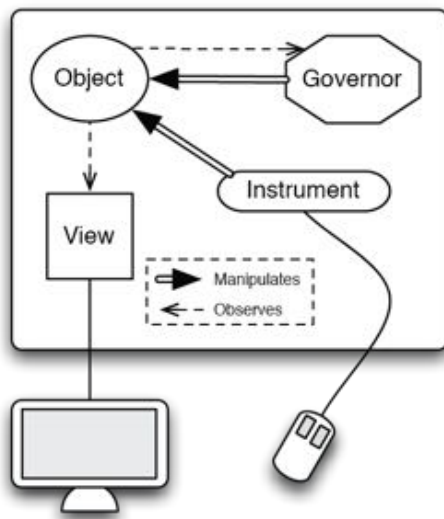


Figure 3.2: Parts of the VIGO framework.

Klokrose and Beaudouin-Lafon presented their architecture framework Views, Instruments, Governors and Objects (VIGO) which directly implements the concepts of UII (Klokrose and Beaudouin-Lafon, 2009). Components are placed into one of the four different categories. The way elements interact with each other is defined by the category they belong to (Fig. 3.2). Objects are data that users are interested in. A view corresponds to a visual representation of an object. Instruments are objects able to change characteristics of objects. Governors listen to object changes and offer information about the validity and effects of an action.

When they introduced this framework, they offered a qualitative analysis of it. They concluded that VIGO is suitable for distribution of interfaces because of how general it is and the possibility of combining and reusing components. They do mention that this flexibility might become a drawback when the amount of components increases.

Later, they worked with Gjerlufsen et al. (Gjerlufsen et al., 2011). Together they develop Substance, an implementation of a data oriented model, and Shared Substance “a distributed application model implemented in Substance”. Interaction done in Shared Substance is based on the VIGO framework. With these models they developed applications and performed a qualitative analysis from an engineering perspective. They found that the VIGO

¹A Swing Architecture Overview - <http://www.oracle.com/technetwork/java/architecture-142923.html> - Visited October 5, 2016

3. RELATED WORK

architecture model was suitable for distributing functionality across diverse surfaces.



Figure 3.3: Three examples of usages of Webstrates. (a) Different views of a presentation document. (b) Editing an image (tablet) that is included in another document (laptop). (c) Controlling a presentation via a tablet. Source: (Klokmore et al., 2015).

Klokmore et al. recently presented a framework for building web applications (Klokmore et al., 2015). Webstrates is compatible with Instrumental Interaction as it considers documents to be the building block of applications. With it, developers can create nestable documents that are synced across different views. With the first version of the system the researchers developed different types of applications with components resembling the ones in the VIGO categories. They created application for writing papers which could display them in two different formats, or views. They implemented a citation instrument which they shared among various users who included it in their applications.

In a live presentation Klokmore showed the possibilities of using Webstrates to distribute user interfaces. While displaying slides in one device, he was able to edit them in real-time in an editor in another one (Fig. 3.3). As shown, this is a very flexible framework that can be used to implement applications that can run on diverse communities of devices. Because of this, and its close ties to Ubiquitous Instrumental Interaction, we decided to use this framework for the implementation of our applications (See Chapter 4).

Now that we provided an overview of work done towards achieving meaningful distribution of user interfaces, we look into the interaction between users and these interfaces.

3.2 Cross-Device Interaction Techniques Studies

Research in the area of cross-device interaction techniques is abundant. This research concerns itself with improving the interactions that enable users to

use different devices together. Numerous projects and prototypes have been developed with the purpose of evaluating them (Alsos and Svanæs, 2006; Hinckley et al., 2004; Hinckley, 2003). Here we outline the most relevant ones.

3.2.1 HuddleLamp

HuddleLamp integrates the ideas from Wellner’s Digital Desk and Weiser’s Ubiquitous Interaction (Rädle et al., 2014). Rädle et al. developed a system in which mobile devices can be assembled into multi-surface ecosystems. Devices are all connected with each other and communicate through a server. Their position and users interactions are tracked with a camera and image processing techniques. The setup is shown in Figure 3.4.

The researchers used HuddleLamp to performed a two phase study to better understand advantages and disadvantages between spatially-aware and spatially-agnostic interactions (Rädle et al., 2015). The first phase of this study involved several focus groups with the purpose of brainstorming about multi-device interactions to achieve tasks such as copying and moving objects between devices. In this part, they found that participants expected interactions between multiple devices to be spatially aware.

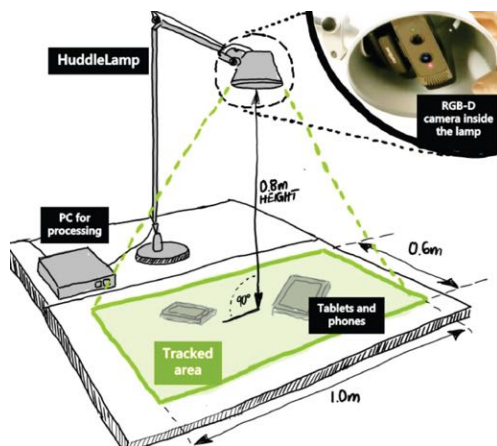


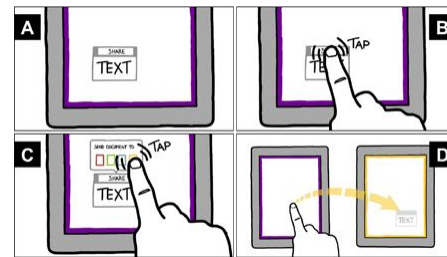
Figure 3.4: The HuddleLamp system requires a camera to track devices and users on a flat surface. It uses a PC for image processing and centralized communication. Source: (Rädle et al., 2014)

Taking the results of the first phase, the second phase was a counter-balanced within-subject study. They tested three conditions of multi-device interaction modalities that were developed with the aid of HuddleLamp. Of these conditions, two were spatially aware and one spatially agnostic.

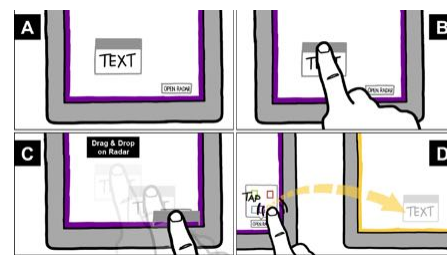
All conditions involved a colored border around the screen of each device to identify it (Fig. 3.5). The *radar view* condition provided participants with a birds-eye view of the tablets and their position, much like a map (Fig. 3.5(c)). In this view, each tablet was shown on a small map in their corresponding position

with their respective color. In *edge bubbles*, bubbles were displayed in the border of each device (Fig. 3.5(b)). Each bubble corresponded to another device and had the color and position in accordance to that other device. The spatially-agnostic technique involved showing a *menu* of color-coded items corresponding to the other devices (Fig. 3.5(a))

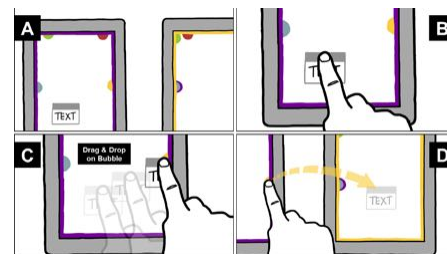
They recruited 12 participants who were each given 5 Apple iPads. Each participant performed 3 different types of tasks, 48 times each, under each of the 3 conditions. These tasks involved duplicating the view of a specific tablet in another one, moving an object from a target tablet to another one and copying a given object from the target to a destination. They found that the spatially-aware interaction were also preferred over spatially-agnostic ones in practice as well. However, there were also differences between the two spatially-aware conditions. Participants reported a higher mental demand and frustration when using the *radar view* than with the *edge bubbles*. The *radar view* was also outperformed and was liked less than *menu* in certain conditions. These results indicated that, even though spatially-aware interactions may be desirable in many cases, these have to be carefully designed and developed.



(a) Menu.



(b) Radar view.



(c) Edge bubbles.

Figure 3.5: Spatially-aware vs. Spatially-agnostic interaction techniques. Source: (Rädle et al., 2015)

3.2.2 Cross-Device Object Movement

Jokela et al. investigated different, more physical, interaction techniques with similar tasks and reached comparable results. They developed three novel ways of transferring visual objects across different devices (Fig. 3.6)

(Jokela et al., 2015). The first approach offered a tray shared by all other devices, similar to a network folder. The second approach, transfer mode, would pair devices up, by drawing a gesture on both of them, to enable transfer of objects between them. In the third approach, device touch, objects from one device could be moved into another by tapping the origin device with the corner of the destination phone.



Figure 3.6: Multi-device object transfer. (a) Tray: a tray shared by all other devices. (b) Transfer mode: pair devices up to enable transfer of objects between them. (c) Device Touch: objects from one device could be moved into another by tapping of the origin phone onto the destination device. Source: (Jokela et al., 2015).

The researchers performed an evaluation with 18 participants who performed tasks with a tablet and two phones. These tasks involved transferring different amount of objects in different kinds of scenarios. They found that participants liked the way these interactions worked in general. It is interesting, however, that participants had clear preferences of certain alternatives on certain scenarios. For example, the touch option was preferred for quick transfers while the tray was preferred for transferring large amount of items. These insights show how carefully these type of interactions have to be designed. Even though the three approaches achieved the same result, they were more suitable in certain specific situations. This is something that we need to keep in mind in our evaluation.

3.2.3 Personal Clipboards

Schmidt et al. explored several interaction styles between a tabletop display and mobile (Schmidt et al., 2012). Of these, some, like PhoneCopy-Paste and PhonePalettes, resembled the concepts of Instrumental Interaction. Tools were placed into individual devices which could be used to perform certain actions. In the study they conducted, participants easily understood this design, even if they did not have previous experience with handheld devices.

The researchers later explored different techniques of achieving the PhoneCopy-

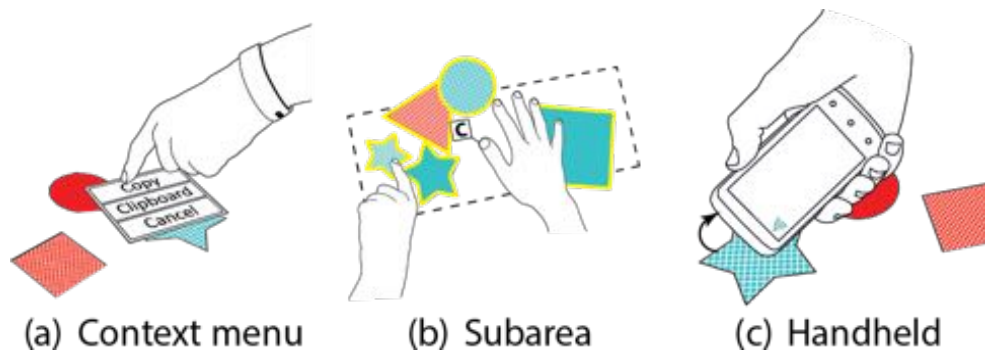


Figure 3.7: Three alternatives for personal clipboards. Two (*a* and *b*) are part of the interface in the tabletop display while the handheld (*c*) option provides a mobile phone to place copied elements in. Source: (Schmidt et al., 2013).

Paste interaction in a collaborative space (Schmidt et al., 2013). They tested three approaches in a study with 9 pairs of participants who performed tasks on a touch capable tabletop display (Fig. 3.7). Participants wore a wristband to identify their actions and used a mobile phone when necessary. Two techniques involved only the use of a tabletop display. The third technique provided users a mobile phone where elements could be copied into and pasted from. They found that the handheld clipboard offered the most freedom and allowed participants to copy faster than in other implementations. This shows that it is worth further exploring the use of handheld devices as containers for instruments in a DUI.

3.3 Cross-device User Behavior Studies

Researchers are eager to understand how users engage with DUIs. Specially now that both the amount of devices per person and projects involving diverse ecologies of devices have increased.

While the previous section investigates ways to improve specific interaction techniques here we explore how cross-device applications are used and the influence they may have upon users' behavior.

Husmann et al. developed a framework with which they were able to track the usage of web interfaces in the wild (Husmann et al., 2016). They used their system to track the usage of an educational web application with over 3000 users. This application did not offer cross-device functionality but still users opened it in several devices or tabs simultaneously. The researchers introduced a multi-device workflow for uploading assignments to a group of 30 students. They were able to detect the usage of this feature among several students and the type of devices they used it with. This study shows a way of obtaining more information about how and when cross-device in-

teractions are performed in the wild.

Hartmann et. al created Pictionaire (Hartmann et al., 2010). Much like the DigitalDesk it merges digital and physical artifacts. The physical objects are integrated into the digital by scanning them with a camera. The digital is integrated into the physical via projections. They developed different interaction techniques involving augmenting a tabletop with different input devices like mice and keyboards (Hartmann et al., 2009).

Afterwards, they conducted two explorative studies. One involved gathering 16 design professionals to investigate how such a system could be integrated into their existing workflows. The other one involved 8 students who worked individually or in groups on a brain-storming task. The researchers observed the participants to find patterns in usage. They found that participants took advantage of both the physical and digital possibilities. For example, they drew physical sketches and then scanned them. Participants also scanned physical objects to integrate them into their annotations.

With this study, the researchers found that enabling physical and digital activities together is desirable for creative work because users can take advantage of the benefits of each world. However, they found that their implementation could be improved. This project focused more on investigating ways of successfully achieving a combination of physical and digital artifacts and not on their influence on user behavior.



Figure 3.8: An example setup of the ActivitySpace. It contains a tabletop display (E), a laptop (A), a phone (D) and two tablets (B, C). All devices and documents associated with them are visible in the configuration space (H, I and F,G respectively). Source: (Houben et al., 2014).

The work that Houben et al. did with ActivitySpace is a “distributed activity-centric information management system” that also resembles the Digital Desk (Fig. 3.8) (Houben et al., 2014). It has a collaborative space where

users can interact with malleable ecologies of devices. They can create and manage applications and resources across different devices.

Researchers conducted a scenario based evaluation with this system. Its main purpose was to gauge the ability of participants to conduct activity-centered work but they found interesting patterns pertaining cross-device usage. There were 9 participants in the study who used the system on a touch capable tabletop display and other devices like laptops, tablets and phones. Participants were recorded while performing several collaborative tasks. The study showed that participants found activities as a suitable organization technique, specially in a cross device scenario. Most importantly, researchers found several reoccurring patterns in the way participants used the system.

Participants relied on the physical aspect of devices to communicate their purpose. For example, they would group devices that contain connected data close to each other, or they would place inactive devices outside of the working area. They also used devices to gather information in the same way they would have done with a physical folder and documents. This work is very valuable since it not only develops a system that showed to be successful but it also provides insights onto users' behavior that can inform further research.

3.4 Conclusion

Extensive research exists in the literature regarding Distributed User Interfaces (Elmqvist, 2011; Hartmann et al., 2009; Gjerlufsen et al., 2011). Most of it focuses on their development or on creating and evaluating novel interaction techniques. Some work has been done in evaluating this type of interfaces and understanding how users would actually take advantage of them.

In this chapter, we presented the most relevant frameworks that exist to distribute a user interface. VIGO and Malai are of special interest to us since they proved to be successful in achieving DUIs while implementing the Instrumental Interaction model.

We also showed an overview of the work done around perfecting interaction techniques for cross-device interfaces. From this, we see that additional devices and spatially-aware interactions are desirable but need to be designed

very carefully.

Lastly, we show different approaches to evaluating the usage of multi-device interactions. We showed that this can be done in the wild, which provides a lot of information but little context, or it can be done in a lab setting, which allows for evaluation of more novel systems.

As we can see, there is yet a lot to be understood about how users actually use distributed user interfaces. The ActivitySpace evaluated a collaborative space based on activity theory concepts. In this thesis, we try to understand how applications designed based on the components of Ubiquitous Instrumental Interaction can influence users in individual work.

Chapter 4

System & Applications

This chapter details the system we used to conduct the experiment. We developed the Distributed Digital Desk (DDD) which is a system that provides different components to create distributed applications. These applications

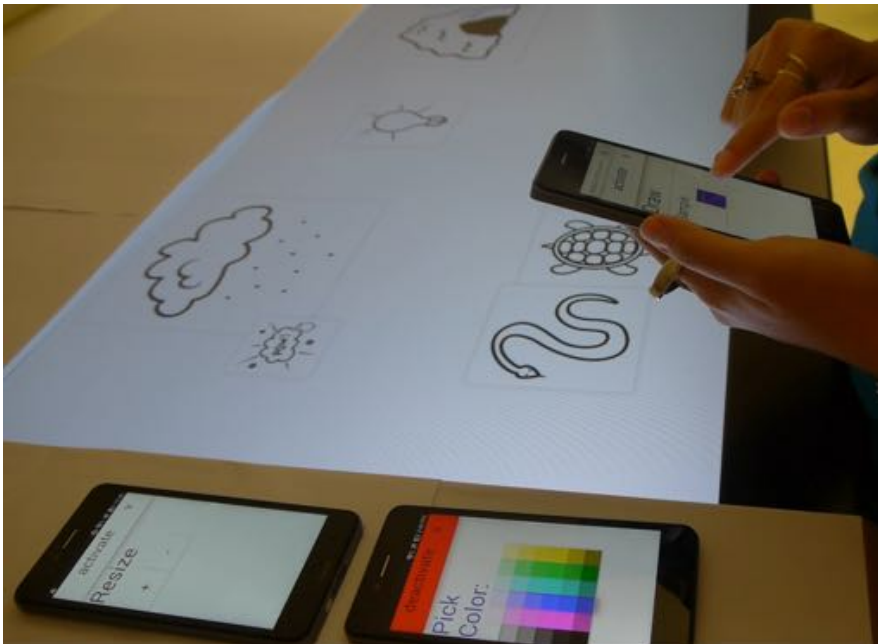


Figure 4.1: Picture of a person using an application created with the Distributed Digital Desk. Three instruments are on three different devices. Two of them are placed on top of the cardboard on the shelf area and one is held by a participant in one hand while drawing with the other one.

are based on documents and instruments as defined in Ubiquitous Instrumental Interaction (UII). Figure 4.1 shows the DDD. We used this system to create three applications. Two of them are distributed while the other one is

a non-distributed application. The latter lets us have a baseline for our study.

The implementation of the DDD uses Webstrates. At the time of development Webstrates was available in v0.0.1¹. We decided to use it because of several reasons: Documents (webstrates) that are created in this framework are web documents and can be opened in any web browser. Since most devices nowadays have a web browser, we can open these documents in almost any device. Documents, as in Instrumental Interaction, are the most important component in Webstrates. As the developers showed, it is possible to create special webstrates, such as instruments, that can be integrated with and act upon other documents.

Following we outline how the DDD works and the types of applications that have been created with it.

4.1 Distributed Digital Desk

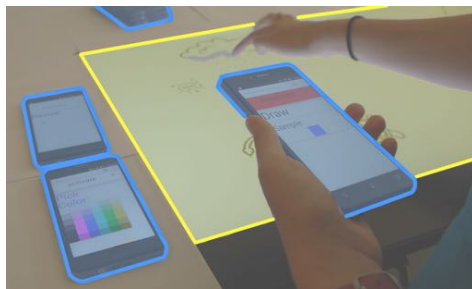


Figure 4.2: Example of possible configuration of instruments (blue) and documents (yellow) with the DDD. Here a user holds a drawing instrument which she is using to draw with on a document in a tabletop display.

The DDD is a system embodying the concepts of UII. Webstrates enables the distribution and synchronization of instruments and documents among different devices (Fig. 4.2).

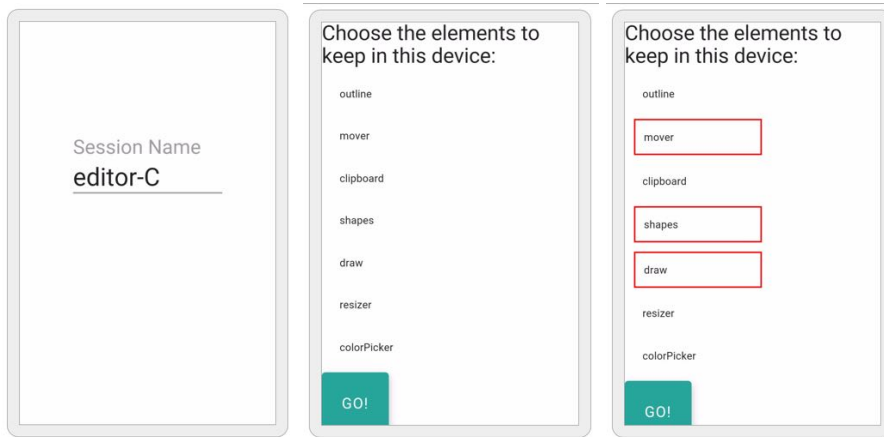
4.1.1 Distributed Application

We can create personalized UII applications with the DDD. In this subsection, we explain the components that make up these applications and how they integrate with each other.

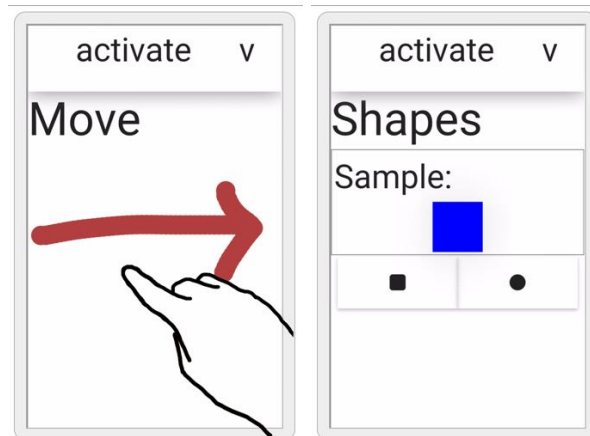
Documents in the DDD are HTML documents that can contain text, shapes and strokes. Instruments are also documents which can be used to edit other documents.

Interaction between a document and an instrument can be enabled by including them in a special kind of document, an editor. This editor listens to

¹Webstrates Github repository - <https://github.com/Webstrates/Webstrates> - Visited September 10, 2016



(a) Enter the name of the editor to work with. (b) A list of documents in the editor is offered. (c) The user can select documents to open.



(d) Selected documents are open. Swiping allows to navigate. (e) The user swiped and obtained the second opened document.

Figure 4.3: A user can open a subset of the documents of an editor in a device. This is particularly useful for opening a subset of instruments to create a personalized toolset as in this example.

changes and events happening in any of the documents inside it and helps them to communicate with each other. Users can create editors and include documents and instruments in them. As long as this editor is open, they can open these documents and instruments in other devices, achieving a DUI. For example, in Figure 4.2 we see a document framed in yellow as well as the drawing, color picker and resize instruments. These are all contained in an editor which is not visible to the user. Since all these documents are in the same editor, they can each be opened in an individual device and used with each other.

Users can create their own custom applications and distribute them in any way they want. The *start* webstrate prompts users to open the application that they want to open in the device they are using (Fig. 4.3). They can choose to create a new or an existing application. If the application already exists they can decide to open it as is or to open a subset of the documents inside it. It is also possible to not only open an individual document in one device but several of them to create a toolbox. Users can swipe through documents when several of them are open in a device (Fig. 4.3(e)).

4.1.2 Instruments

Most instruments have the same structure (Fig. 4.4). They can be used if and only if they are in active mode. Instruments are activated by pressing the activation button. They also have sub-instruments that define special behavior. For example, the shapes drawing instrument has square and circle sub-instruments.

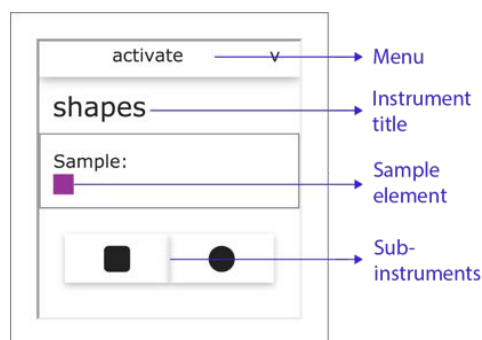


Figure 4.4: Rendered instrument and its parts. The Menu contains an activation button to turn the instrument on and off as well as a dropdown to change the open instrument. The sample element shows how content created with this instrument will look like. In this case, created shapes will be purple. The sub-instrument further define how the instrument will behave. In this case, shapes can be squares or circles.

The instruments in the DDD can be separated into two categories, content creating and content editing. Content creating instruments have a sample element. This element can be edited by any of the content editing instruments. When a content creating instrument is used, it will query all attributes of the sample element and set the same values for the object being created. For example, when a shapes instrument creates a circle this circle will be yellow if the sample element is yellow.

The DDD includes 9 instruments (Fig. 4.5):

- **Mover:** Moves elements around the screen by pressing and dragging.
- **Color Picker:** Changes colors of elements, text, shapes and drawings. It is also useful to change the sample element of other instruments.

- **Resize:** Used to resize elements: text or shapes. Changing the size of the brush's sample element changes its thickness.
- **Text Styler:** Changes how text looks like. Has bold, italics, underlining and stroking sub-instruments.
- **Clipboard:** Can cut, copy, paste, and delete elements. These elements can be parts of a document or documents themselves. It keeps a history of all the elements that have been interacted with so that users can access them later.
- **Brush:** Draws strokes. The strokes have the same color and width as the sample element.
- **Shapes:** Draws two types of shapes, squares and circles. Shapes have the same color as the sample element. The size of a shape is set by pressing and dragging on creation time or with the resizing instrument.
- **Text Inserter:** Inserts text in shapes.
- **Opener:** Opens new documents in an application.

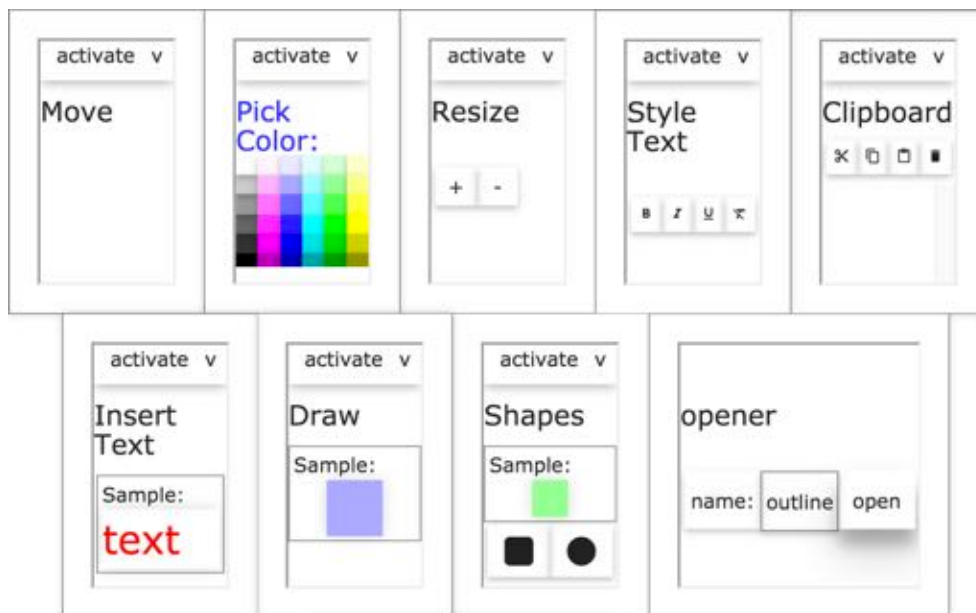


Figure 4.5: All implemented instruments rendered in a browser. Content editing instruments on the top. Content creating instruments on the bottom.

Users can also change the instrument that is open in a certain element by pressing the dropdown menu next to the activation button (Fig. 4.6(b)). This can be useful for switching between instruments that are open on a certain

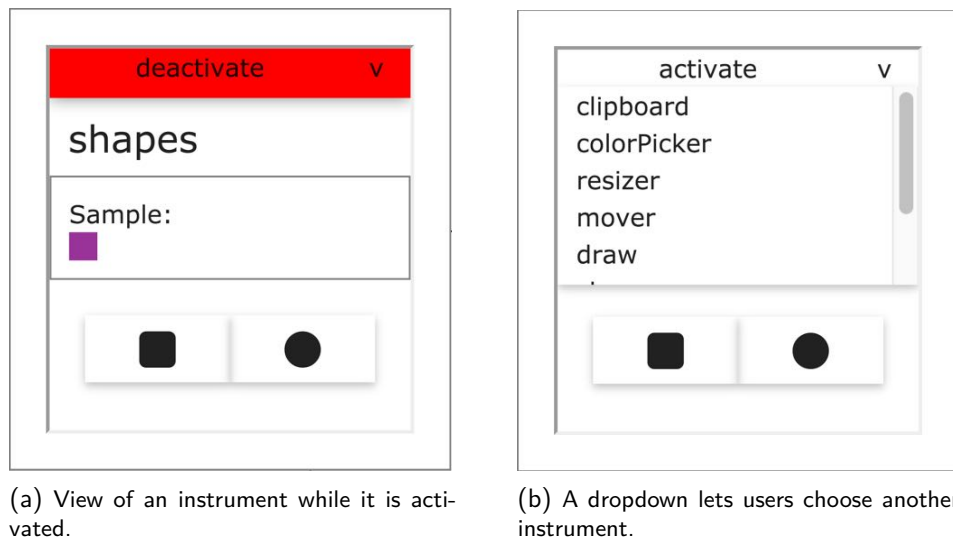


Figure 4.6: Activation and interchanging of an instrument.

device.

It is also possible to create new instruments with a special webstrate, the *instrument-editor*. Here, users can define the name of an instrument, how it should look like, and what it should do. Since the functionality of an instrument can only be defined by writing code at the moment this is a feature used just for development purposes.

4.1.3 Sample workflow

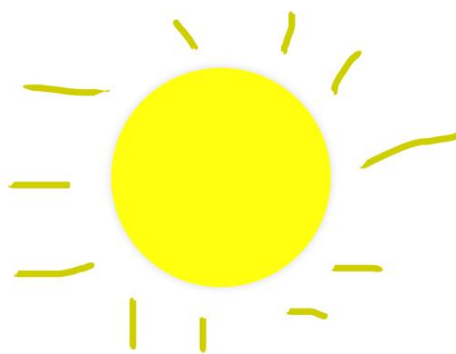


Figure 4.7: Example drawing that can be achieved with the applications.

We setup an application with the shapes, color picker, brush, resize instrument and an empty document. We can then use separate phones to open each instrument, while we open an empty canvas on a tabletop display. To create a sun like in Figure 4.7 we could use the brush and the shapes instruments. A way of achieving this is as follows. We use the shapes instrument to draw the circle. First, we activate the color picker, choose yellow, change the shapes instrument's sample to yellow.

low and deactivate the color picker. Then, we activate the shapes instrument, draw a circle in a document and deactivate it. Later, we activate the resize instrument, shrink the brush's sample element, and deactivate the resize instrument. We then activate the brush, draw lines around the circle and deactivate it. After realizing the lines are not the right color, we can activate the color picker, change its color to another yellow, change the color of the lines and finally deactivate this instrument too.

4.2 Toolbar Application

We are interested in understanding users interactions with instruments and how working through them influences their behavior and results. To do this, we have to also observe participants working in an environment where the interface does not explicitly make a separation between instruments. We created a control application, *toolbar* from now on, which is closer to classical WIMP interfaces that are part of common software suits, like Paint and Powerpoint. Even though it is also created with the DDD, it is only one document that contains all the functionality (Fig. 4.8).

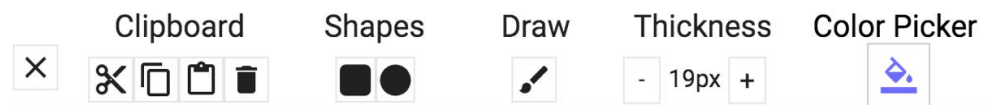


Figure 4.8: The toolbar has different tools. A clipboard with cut, copy, paste and delete. A drawing shapes mode for squares and circles. A brush. Changing the thickness of the brush. Tool to change the color of brush, shapes, and objects.

For comparison purposes we implemented the same functionality provided by the distributed applications. We excluded text related instruments, as well as the opener, since this application was developed after we designed the experiment (see Subsection 5.2.1). We surveyed several computer graphic applications (Paint, Powerpoint, Photoshop, and Google Drawings) and decided to adhere to certain conventions. Objects can be interacted with by first selecting them. Once they are selected, they can be moved by pressing and dragging, and resized by pinching gestures. A toolbar offers the rest of the functionality.

4.2.1 Functionality

From left to right the toolbar has a clear button, clipboard, shape drawing tools, a brush, a thickness setting for the brush and a color setting for shapes

and strokes (Fig. 4.8).

Pressing the clear button will exit any mode the user is in and will deselect any selected objects in the canvas.

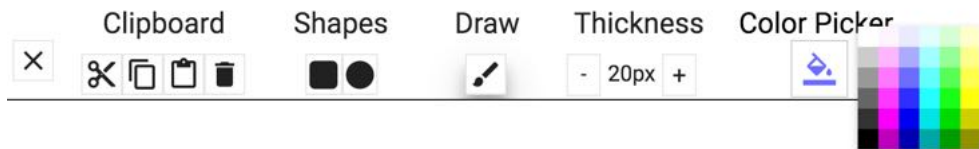


Figure 4.9: Elaborate view of the toolbar. When a mode is active a shadow is shown below it (see brush icon). The only hidden menu are the colors of the color picker, shown here.

The clipboard can cut, copy and delete a selected object. It also can paste the last cut, copied or deleted object into the selected object.

The shapes, square or circle, mode can be turned on by pressing the respective button. It can draw a shape inside of another object. As in the other applications a shape is created by pressing and dragging away from the starting point, which will enlarge it. This shape will have the color of the current settings. The mode is turned off after a shape is drawn or by pressing the button again.



Figure 4.10: A stroke is selected. All other objects' opacities decrease. The values for thickness and color of that object are shown in the settings.

The drawing mode can be turned on by pressing the brush button. We can see that the mode is on because there is a shadow below the button (Fig. 4.9). When in drawing mode, pressing and dragging will result in a stroke inside of the object where this stroke started and no further. A stroke will have the thickness and color of the current settings. This mode is turned off by pressing the brush button again.

Pressing the color bucket shows a color picker with the available colors (Fig. 4.9). Choosing a color will hide it again and change the color of the

bucket.

Users can select and interact with one object at a time (Fig. 4.10). Whenever an object is selected, all other objects' opacities decrease. The values of thickness and color of the object, if applicable, are shown in the settings. Objects' color and thickness can be changed after they have been created by selecting them and changing the settings. The object can be de-selected by pressing the clear button or pressing the background.

4.2.2 Sample Workflow

We can draw the same sun as in the DDD (Fig. 4.7). First we change the color to yellow in the settings. The circle mode is turned on and used to draw a circle. We turn the brush mode on. With the settings, we decrease the thickness of the brush. We draw the lines around the circle. After realizing that this is not the right color, we turn off the drawing mode. We select each line and change its color in the settings.

The two distributed applications and the toolbar application allow us to conduct a comparative study. We can use them for the study, since they offer the same functionality but are related to different design paradigms, UII and WIMP respectively. With this experiment we expect to gain a better understanding of the influence of Ubiquitous Instrumental Interaction on user's behavior patterns in creative work.

Chapter 5

Evaluation

We want to understand the influence of Ubiquitous Instrumental Interaction (UII) on users' behavior patterns in creative work. UII has been studied in depth as an architecture framework and has been found to be suitable from a developer's standpoint. Instrumental Interaction, as well as Distributed User Interfaces (DUIs) have been evaluated in collaborative setups. However, little work exists in the literature when it comes to studying UII from the users' point of view. We chose an individual setup where users perform creative sensemaking tasks. In this chapter, we elaborate on the goals of our evaluation and how it was designed and conducted. We conclude by analyzing the results, using Activity Theory and Instrumental Interaction as frameworks to guide and organize our analysis.

5.1 Research Question

Our main research question is:

How does Ubiquitous Instrumental Interaction influence users' behavior in creative sensemaking tasks?

We want to observe changes in participants' behavior when working on applications based on UII as opposed to conventional WIMP applications. To do this, we focus on three more specific questions regarding the influence of UII on participants' interaction patterns, the problems they encounter and their user experience and task load. Changes in interaction patterns may show us if users adapt the way they work depending on the type of application they are dealing with. Problems they encounter help us pinpoint issues in the applications as well as analyze the way participants cope with them. What participants do when they are faced with a problem is crucial

since it may lead to them learning and better understanding of how an application works. Finally, user experience and task load will aid us to better understand the way participants felt about each application from their point of view.

Specifically our sub-questions are:

RQ1 How does Ubiquitous Instrumental Interaction influence users' interaction patterns?

RQ2 How does Ubiquitous Instrumental Interaction influence the nature and consequences of problems encountered?

RQ3 How does Ubiquitous Instrumental Interaction influence user experience and task load?

The dependent variables, divided into the different research questions are as follows:

RQ1: In general we want to observe changes in the way tools and instruments are used. Changes in length can show us whether certain instruments and tools are used more or less in certain situations. We expect that the alternation and order of instrument usage will show us reoccurring patterns and display relations between certain instruments. Finally, the objectification of instruments is related to the treatment of instruments as the objects of actions. We are interested to see whether the occurrence of this phenomenon is influenced by the presence of physical instruments as opposed to digital ones. We discuss these measures by analyzing and visualizing log and video data and comparing stories participants created.

Specifically, to analyze and observe interaction patterns, we measure:

- *Length* of instrument usage.
- *Alternation* between instruments.
- *Order* of instrument usage.
- *Objectification* of instruments.

RQ2: *Breakdowns* participants encounter while performing the tasks. Measured by observing and encoding video recordings.

RQ3: *User experience* and *task load* as measured by the User Experience Questionnaire and the NASA-TLX questionnaire and informed by our observations and user comments.

The independent variable is the type and presentation of tools. In this specific study, we compare three different applications, see Chapter 4. We present a classical approach with a toolbar and settings and a working area, all in one surface. To better understand instrument usage we present two applications based on UII, created with the Distributed Digital Desk (DDD). One contains instruments and a document, all in one surface. The other one is made up of instruments in individual physical devices and a document in another surface.

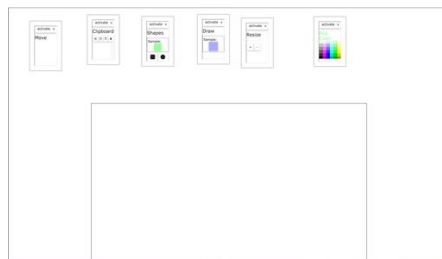
It is important to keep in mind that the expertise of participants may be a major influence on their performance. We try to diminish the effect of expertise by choosing a task and offering tools that are simple enough for all participants to feel comfortable with.

5.2 Study Design

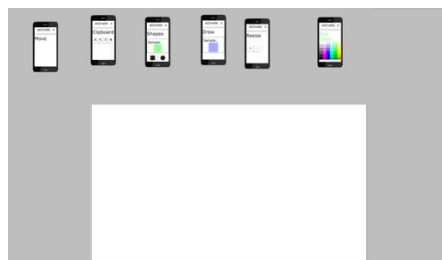
To answer our research questions we designed a study. The goal of our study was to help us understand how the behavior patterns participants employ in creative work are influenced by the introduction of instruments. We also want to know whether the distribution of documents and instruments among separate devices has an influence on participants' behaviors or not. We decided to observe users' behavior patterns while working with three different applications. To avoid the results being influenced by differences between participants we expose all participants to all conditions in a counter-balanced within-subject study.



(a) Toolbar setup. Toolbar is above the canvas area. A cardboard (grey area) is placed around working area.



(b) Movable digital panels containing instruments are placed above canvas area.



(c) Movable devices containing instruments are placed on the shelf area on top of a cardboard (grey area) around the canvas.

Figure 5.1: Schematic overview of all conditions. All conditions are based on a tabletop display.

5.2.1 Conditions

We want to understand the influence of instruments and their physical presence upon users behavior patterns in creative work. Hence, we must be able to compare a Ubiquitous Instrumental Interaction (UII) application with physical instruments with a more classical interface. We created a toolbar application with tools and settings for this purpose. However, comparing this with a DUI with physical instruments would lead us to comparing two factors: the instruments and their physicality. To overcome this, we created an intermediate application where instruments are not physical but digital. This helps us better understand where the differences in behavior patterns truly comes from.

For the study, we created an overarching system that contained the necessary functionality for each condition. We created a script that would save all documents and restore them to their original state. This was important to provide the same experience for each participant and to avoid losing data. Following is a description of each setup.

Condition 1: Toolbar

The toolbar setup (*toolbar* from here on) offers the tools and settings as described in Section 4.2. The toolbar is placed centered above the canvas (Fig. 5.1(a)). A cardboard is placed on the rest of the shelf area not used up by the toolbar (Fig. 5.3(a)).

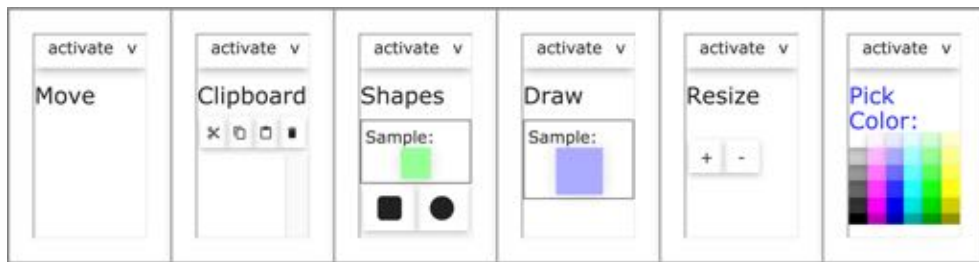


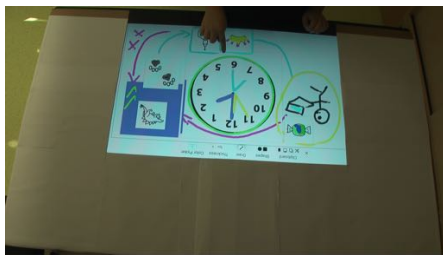
Figure 5.2: All instruments available during the experiment.

Condition 2: Digital Instrument Panels

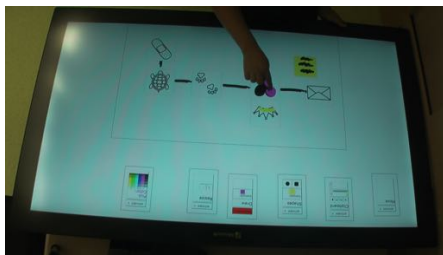
The digital instrument panels setup (*panels* from now on) is the intermediate setup used between *toolbar* and physical instruments. The DDD instruments are placed inside boxes alongside with a document on a tabletop display (Fig. 5.1(b)). These boxes were given no special characteristics, they can be moved, colored and resized as any other element. To make the conditions comparable, we restricted the area in which the panels could be moved in.

Since phones cannot be directly placed on top of the tabletop display, the panels can only be placed around the document and not inside it.

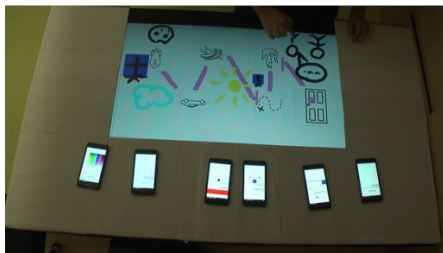
6 instruments are offered to participants (Fig. 5.2). A keyboard, digital or physical, could have distracted participants, so we did not include the text related instruments. The opener was also left out to keep interaction more focused and comparable to *toolbar*.



(a) Toolbar setting.



(b) Panels setting.



(c) Phones setting.

Figure 5.3: Settings viewed from the camera's point of view.

in one key way. The same instruments were placed in individual devices. A cardboard was placed on top of the shelf area to offer a surface for the devices to be put on (Fig. 5.1(c)). Instruments could also be moved in this condition, but the size and color of their containing boxes (the phones) could not be changed. The phones were only to be placed on top of the cardboard and not the tabletop.

To avoid participants reaching unexpected situations they could not revert we reduced the possible objects certain instruments could act upon. With the DDD instruments participants could, for example, have deleted certain elements of another instrument, like their title or a sub-instrument. Even though this allows for a highly customizable interface, we did not want participants to feel overwhelmed, specially since no undo capabilities were available. We restricted most instruments to only be able to act upon user created content, sample elements or panels containing instruments.

Condition 3: Physical Instrument Phones

The physical instrument phones condition (*phones* from now on) only differed from the previous version

5.2.2 Setting

Participants used the Microsoft Perceptive Pixel 55" (1920 × 1080 pixels) as a desk surface, parallel to the floor (Fig. 5.4). This tabletop display had a working area (*canvas*), of 30" across with a 16:9 ratio, which was centered at the bottom.

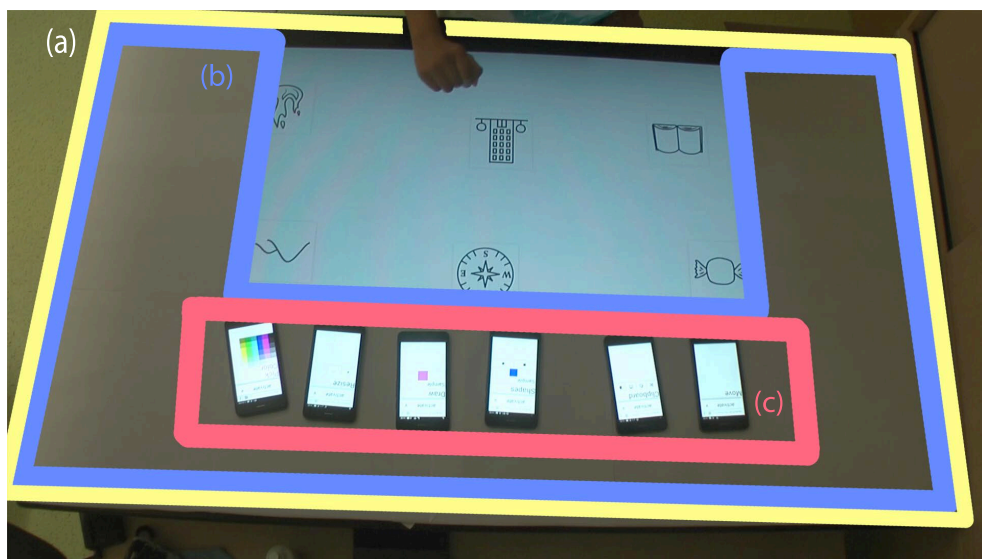


Figure 5.4: Screenshot of recorded video showing the setting of the experiment conditions from a bird's eye view. There is an interactive tabletop display (a). This tabletop display may have a cardboard on top (b). Phones contain instruments if necessary (c).

On top and to the sides of this canvas there was an area (*shelf space*) for other interface elements, this area was adapted depending on the condition. When an area of the tabletop display was not to be used, a cardboard, cut in the same shape, was placed on top of it to avoid users pressing on it by mistake. Six identical mobile phones, Asus Zenfone 5" (1920 × 1080 pixels, weight: 145g), were available to distribute the user interface in one of the conditions. A local server was run from a MacBook Pro (Retina, 15-inch, Mid 2014) to which all devices connected to through the local network.

Participants stood in front of the tabletop display. Opposite to them there was a camera recording a birds-eye view of each condition. Figure 5.3 shows all three settings. For *panels* and *phones*, instruments were initially placed above the canvas. These instruments could only be moved inside the shelf

area.

5.2.3 Task

Participants performed the same task under each of the three different conditions, *toolbar*, *panels*, and *phones*. The task was inspired by the “Story Cubes¹” game. In this game, players roll dice which include a small sketch on each side (Fig. 5.5). The player proceeds to order the rolled images to tell a story. For our tasks, we gave participants 10 minutes and 6 images inside the canvas under each condition. With these images and the tools at hand they were asked to create a story. They were encouraged to use all tools; to draw shapes and strokes, color, move, resize, cut, copy, paste, and delete elements.

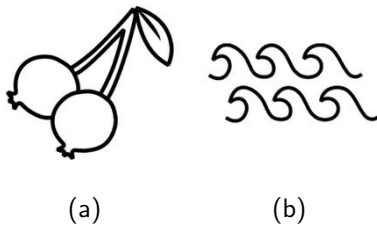


Figure 5.5: Two sample images from the Story Cubes.

Before each task, we showed participants how to perform all the operations. In this exploration session, we showed them each application with only two images (Fig. 5.5). We first moved these images to have the cherries above the waves. Then, we enlarged the waves and shrunk the cherries. Later, copied and pasted the waves twice to obtain a larger area of water. We proceeded to

color the shapes with different brush colors and widths. We also showed how to paste objects inside other objects by pasting the cherries inside the waves, and then proceeded to delete them. Finally, we showed that instruments, panels or physical, could be moved or switched. With this demonstration we showed all operations they needed to create and edit content in each of the conditions. We also prompted them to explore and ask questions before starting the tasks.

5.2.4 Participants

We decided to recruit university students because the study did not require expertise in any area. Posters and flyers were put around the university calling for students to take part in a study involving creativity (Appendix A.6). Participants contacted us through the provided e-mail address. We recruited 20 students for the study.

¹Rory’s Story Cubes: <https://www.storycubes.com/play> - Visited October 14, 2016

Activity	Time
Description	3 min.
Exploration	4 min.
Task	10 min.
User Story-telling	1 min.
Post-Questionnaire	5 min.
Total	23 minutes

(a) Time allotted for each condition.

Activity	Time
Welcome	3 min.
Pre-Questionnaire	5 min.
Condition $\times 3$	3×23 min.
Interview	10 min.
Farewell	3 min.
Total	90 minutes

(b) Time allotted for experiment.

Table 5.1: Breakdown of time expected per planned experiment activity.

5.2.5 Procedure

We invited each participant to participate in the study in the same room. This room contained the Microsoft Perceptive Pixel, to perform the tasks in, and a desk with a chair, to answer the questionnaires and the interview. Each session lasted around 90 minutes, broken down as shown in Table 5.1. Participants were welcomed and offered a consent form explaining the procedure of the study (Appendix A.1) and a short demographic questionnaire.

Each participant performed the same task under all the conditions. The order of the conditions was one of the 6 possible permutations of the 3 conditions. Since we had 20 participants, each permutation was done by 3 different participants while 2 permutations were done by 4 participants.

For each condition participants were explained the task before it started. Afterwards, they were shown how the application at hand works with two images (an image of waves and an image of two cherries) (Fig. 5.5). They had a chance to interact with the application to get familiar with it and ask questions. When they communicated they were prepared, they received six randomly chosen images to create a story within approximately 10 minutes. Each task was video recorded. Participants could ask questions if needed and were able to stop before the 10 minutes had elapsed, although they were encouraged to use all the available time.

When they were done, they told the story they had created and later filled out the NASA-TLX and UEQ questionnaires (see 5.3.1). After all tasks were completed, the experimenter conducted a short interview, asking about their experience, findings, and preferences between the different conditions. Fi-

nally, they were reimbursed for their time.

5.3 Analysis

In this section, we elaborate on how we use the experiment previously outlined to obtain the data we needed to gain insights into our research questions. To understand changes in frequency and order of instrument use for **RQ1** we mostly use logging. We assess the problems in interaction for **RQ2** via observations, videos, and interviews. Questionnaires gave us a standardized and reliable way to measure user experience and task load for **RQ3**. The following subsections explain how we collected and processed this data.

5.3.1 Data Acquisition Sources and Processing

Here we explain and discuss the data acquisition methods we chose. We used different types of methods in order to best triangulate our results.

Observations

We observed each participant while they performed each task and took notes of outstanding behavior. These observations were useful to gain more insights into users' behavior during the interview. They also helped to find common factors among participants for later analysis.

With these observations we were able to take a first step towards answering our research questions. We could observe how instruments were used and noted common and outstanding usages and patterns. We also noted breakdowns and special usages of instruments occurring during each session. With these observations we could ask more insightful questions to participants during the interviews. This helped us obtain more information beyond standardized questionnaires.

These observations were also useful to decide upon a video analysis strategy which we outline later on.

Interviews

At the end of each session, we conducted and recorded a short semi-structured interview. This interview was based on the questions in the Appendix A.5 and the aforementioned observations. This interview was important to understand the preferences of participants from their own point of view. It was

Event	Code	Categories
Breakdown	B	Activation / Other
Physical use	P	Moving / Lifting
Special instrument use	I	-

Table 5.2: Codes to encode the videos of each session.

also helpful to ask questions clarifying actions they took and mental models they created after they had performed the tasks, as to not influence their performance.

We asked questions about the strategies they used during the sessions to better understand their behavior, relevant for **RQ1**. To better understand their experience (**RQ3**) we asked them to mention what they liked and disliked from each application. Here, it was useful to have observed them, since we could start a conversation about the problems they encountered (**RQ2**) and how these influenced their experience.

We later performed a qualitative analysis of the interviews and broke them down into snippets. This helped us create a topic-based clustering of participants' comments to find common patterns and issues.

Video Recording and Video Coding

We recorded a video of each participant performing the task under each condition. We considered the insights offered by (Bødker, 1995) on the use of Activity Theory when analyzing video recordings. Our encoding focused on breakdowns and focus shifts (see Section 2.1). However, after encoding the videos we realized that focus shifts were too hard to define. It is not possible to identify what actions participants are focusing on or performing only by observing them. Because of this, we decided to use the video encoding to observe *breakdowns* for **RQ2** and *physical* and *special* use of instruments for **RQ1**.

Table 5.3.1 shows an overview of the coding scheme we decided upon to gather this information. We observed that most problems that participants encountered were related to the activation and deactivation of modes or instruments. Thus, we found that it was best to divide breakdowns into two

categories: *activation* of instruments or modes and *other* breakdowns.

The *physical use* code denotes events in which participants treated instruments as physical objects by *moving* or *lifting* them. This is interesting for **RQ1** as it shows instruments as the objects of actions.

The *special instrument use* coding corresponded to interacting with an instrument beyond the possibilities explained in the sample session. For example, the deleting sub-instrument of the clipboard was only shown to work on elements inside the canvas, however, several participants used it to remove elements inside of other instruments. These types of interactions are specially interesting, since they may show us participants internalizing instruments as the reification of an action.

Questionnaires

We used three different questionnaires throughout our experiment. Participants filled out a demographic questionnaire in the beginning of the session. Its purpose was to understand the background of the users with respect to experience with computers, specially the use of mobile and touch devices. This information could be important to identify outliers or identify if certain previous knowledge influences participants' interactions with the applications.

We used both the NASA-TLX (Hart and Staveland, 1988) and User Experience Questionnaire (UEQ) (Laugwitz et al., 2008) as they are simple to administer. They are also a good choice since their usage is wide spread and accepted in the literature, which allows for a common baseline. Both these questionnaires are used to answer **RQ3**, in relation to user experience and task load.

The NASA-TLX questionnaire is useful to further understand participants' perception of the workload under each condition (Hart and Staveland, 1988) (Appendix A.3). This questionnaire is made up of 6 questions about Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration that participants may have experienced during a task. For each question the participant is asked to give their own subjective value in a scale. The total task load can be obtained by combining these dimensions.

The UEQ gauged the usability of each of the applications (Laugwitz et al., 2008) (Appendix A.4). This questionnaire has 26 bipolar scales and participants rate a system with respect to each of them. For example, a scale could

have “attractive” and “unattractive” on either side and the participant can choose any of the seven levels between them. The scales fall into one of these categories: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. The questions falling into each category are combined to calculate the category’s score. These categories can later be used to further understand and compare the usability of the applications.

Data Logs

We automatically logged interactions of participants with the applications. We were specially interested in the actions performed, how long they lasted, and their order to help us understand **RQ1**. For this we logged:

- Activation and deactivation of modes / instruments.
- Usage of instruments and information related to this action; sub-instrument being used, element being acted upon, and cursor position.
- Clicks on any element. Relevant to know when an element is selected in *toolbar* or when a sub-instrument or mode is selected.

Each session’s condition had a corresponding automatically generated file. Each row in a log file is made up of a timestamp and a message falling into one of the aforementioned 3 categories. For example: 1470046540332: resizer more-diagonal image-56 shows that the resize instrument was used on the object with ID image-56 to enlarge it at 1470046540332. For the clipboard and the color picker, individual usages are logged, while for the other actions events are logged throughout the performance of the action.

The logs had some noise. Several files had events logged before the actual beginning of the session and after the actual ending of it. We were able to programmatically remove these events by going through them. We created a program to split the files any time there was a gap longer than 120 seconds and kept only the longest file. The time elapsed in each of the files (last timestamp - first timestamp) was the same, within 20 seconds, as the time elapsed in their corresponding videos. Hence, we confirmed that the logs in each file were correct, the start of the video and the first action participants took were not always simultaneous.

We later parsed the log files with Python² to create standardized objects containing this information. Then, we used these objects for statistical analysis

²Python 3 - <https://www.python.org/download/releases/3.0/> - Visited September 21, 2016

and visualizations.

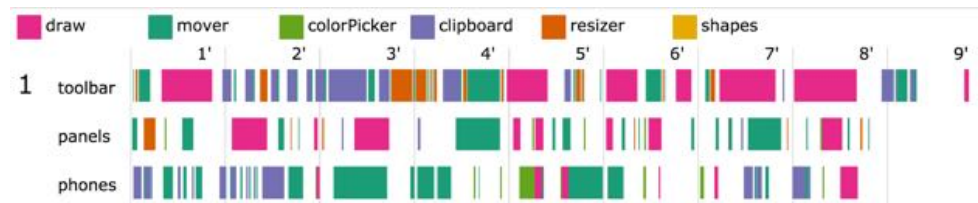


Figure 5.6: A scarf plot for the first participant in each condition. Time is encoded horizontally while the usage of instruments is shown by a rectangle as long as it was used.

We created visualizations using D3³. For each participant in each condition we created a scarf plot (Fig. 5.6). In these plots the time corresponds to the x-axis, with vertical lines identifying the pass of each minute. Rectangles of equal height correspond to the usage of an instrument. A rectangle starts when an instrument's usage starts and grows towards the right, until the participant stops using it. All consecutive usages of an instrument are grouped into one rectangle, even if there were usage gaps in between. So, for example, if a participant used the mover from minute 1 to 2, paused and then used it from minute 3 to 4 there will be a rectangle from minute 1 to 4. A new rectangle is started when the participant switches instrument. If several instruments are active at once, and hence used in parallel, overlapping rectangles are created.

Each individual condition of each participant corresponds to one plot. All plots are stacked vertically. Participant's plots are grouped together visually by being closer to each other. All visualizations are attached to this thesis as an Appendix A.7. With this visualization we gain a first understanding of prominent instrument usages and patterns that inform our decisions regarding what to investigate next. It is specially useful to dive into answering **RQ1**.

5.3.2 User Created Story

For **RQ1** we are interested in understanding shifts in instrument and tool usage. For this, we look directly at how participants used instruments. However, it may also be interesting to look at the story created by each participant. From the images that they created under each condition we can gain some insight into how often they used certain tools, like the brush and the

³D3 - <https://d3js.org/> - Visited September 21, 2016

clipboard, for example. With this in mind, we saved all the original documents corresponding to each of the stories created by the participants.

5.4 Results and Discussion

We organized all the data into four categories. These correspond to demographic data and each of our three research questions.

The demographic questionnaire employed in the beginning of each session informs the results of the demographic data analysis.

The analysis corresponding to the usage of instruments and tools and their order (**RQ1**) is based on logs, video encoding, observations, generated story, and interview information. Logs and video encoding give us quantitative data about how often, for how long and the sequence the instruments and tools were used in. The interview information, generated story and interview information enable us to conduct a qualitative analysis of the aforementioned data sources.

We also investigated the breakdowns encountered by participants (**RQ2**) from both a quantitative and a qualitative point of view. Video encodings conform the source of quantitative data. The qualitative sources are our observations and the data collected from the interviews.

Finally, we analyze user experience and task load (**RQ3**) with the UEQ and NASA-TLX questionnaires, from a quantitative angle, and with the interviews and observations from a qualitative angle.

We used IBM's SPSS⁴ to do further statistical analysis on the video and logs data. If not stated otherwise statistical significance analysis was done via one-way ANOVAs and one-way repeated ANOVAs for two or more cases being compared respectively. For more than two conditions pairwise post-hoc comparisons were used, with a Bonferroni correction, reported p-values in this case are multiplied by the amount of condition pairs.

We did basic calculations and visualizations (bar graphs) in Microsoft's Excel⁵.

⁴IBM SPSS - IBM Analytics - <http://www.ibm.com/analytics/us/en/technology/spss/#what-is-spss> - Visited October 3, 2016

⁵Microsoft Excel - https://en.wikipedia.org/wiki/Microsoft_Excel - Visited October 3, 2016

The following subsections present the results we obtained and discuss them to answer each of our research questions.

5.4.1 Demographic Data

For the study, we recruited 20 participants, 9 male and 11 female. Their average age was 25.15 years (SD = 4.22 years, between 20 - 39 years). 16 of the participants were students while the other 4 were university research staff. 10 of the participants were lightly visually impaired but wore glasses as necessary, so this did not interfere with the study. 2 participants were left-handed while all others were right-handed.

All of them reported to have experience with touch devices, 19 reported using them daily and the other several times a week. While all participants had experience with handheld touch devices, only 2 reported in the interviews to have had experience with multi-device environments.

5.4.2 RQ1: How does Ubiquitous Instrumental Interaction influence users' interaction patterns?

In this subsection, we look at the actions participants performed to obtain an answer to **RQ1**. To answer this question, we observed the following four dependent variables:

1. *Length* of instrument usage.
2. *Alternation* between instruments.
3. *Order* of instrument usage.
4. *Objectification* of instruments.

Length of Instrument Usage

Our first step towards understanding the effects of DUIs and UII upon creative sensemaking is to observe changes in how often tools are used. Do participants use certain tools more under certain conditions? To answer this question we mostly use the log data to analyze the amount of time each tool was used under each condition. A usage of an instrument in this case is detected by a log entry for that instrument. We create an accumulated sum for each tool under each condition and compare them. Later we look into the stories created by participants and the interviews conducted at the end of each session to confirm these results from a qualitative standpoint. We

finally discuss these results.

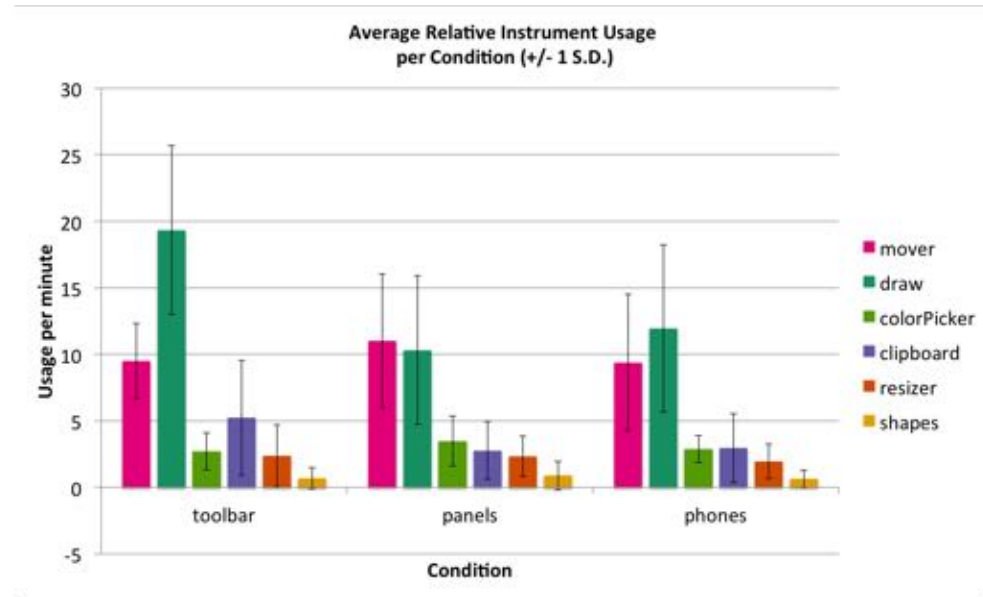


Figure 5.7: The average amount of times per minute an instrument was used showing 1 standard deviation. The instruments are grouped per condition to examine the difference of usage of instruments inside each condition.

First, we compare differences in the general usage of instruments. Hence, we analyze the amount of usages per minute of instruments, regardless of the condition. This leads us to establishing a general understanding of instrument usage to facilitate further comparisons.

Figure 5.7 shows a bar graph showing the average amount of times per minute each instrument was used under each condition. Bars are grouped per condition to visualize common patterns occurring in all conditions. It shows that in all conditions, the mover and brush were used the most. This may be related to the fact that the images that were given to participants were simple line sketches that were randomly ordered in the canvas. Most participants started a session by moving the images into a certain order to afterwards fill them in with color. They also found that these two instruments were the most important. P5 mentioned that she “painted and moved a lot” and P8 mentioned that “drawing was very important”. P17 said she “ordered pictures and connected them with drawing” as her strategy.

We look more closely into the changes in usage of specific instruments across conditions. Figure 5.8 shows again the average amount of times instruments

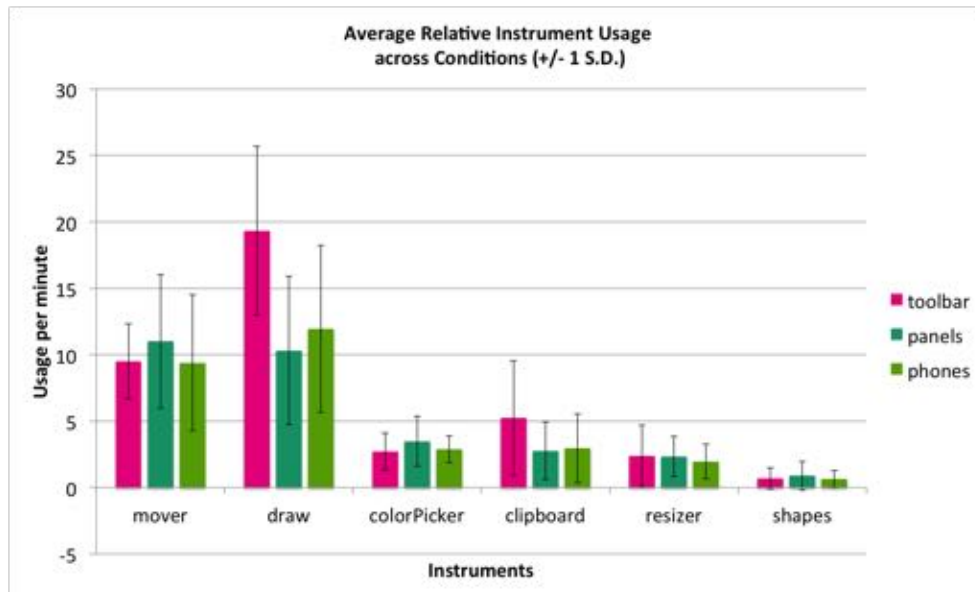


Figure 5.8: Average amount and a standard deviation of the usages per minute of instruments across conditions. With this view we can better understand the differences in usage of instruments across conditions. While most instruments had a similar usages it is clear that the draw instrument was used more in *toolbar* than in the other two conditions.

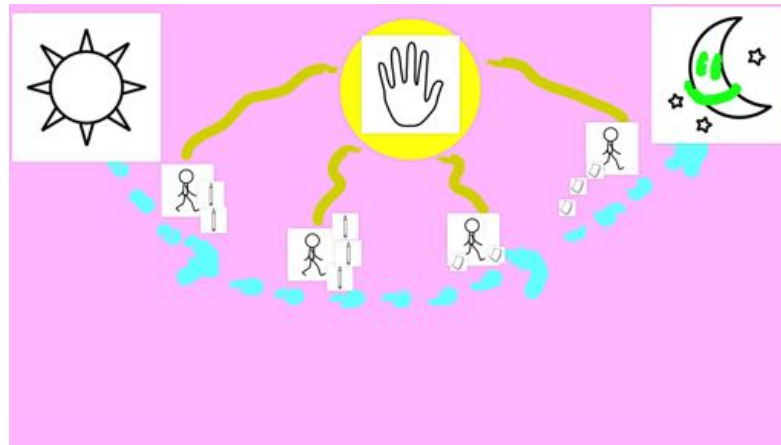
were used per minute under each condition. In this case, they are grouped by instrument to better visualize differences occurring between conditions.

The only statistically significant differences are the usage of the brush ($F(2, 38) = 22.663, p < .05$) and the clipboard ($F(2, 38) = 4.876, p < .05$). Pairwise post-hoc comparison of the brush usage proves to be statistically significant for the difference between *toolbar* and *panels* and *phones* (both $p < .000$) but not between *panels* and *phones*. Hence, we can conclude that the brush was used the most in *toolbar* while similarly in both *panels* and *phones*. There was no statistically significant difference between the pairwise post-hoc comparisons for the clipboard.

These results are supported by participants' statements in the interviews and their created stories. P20 said that "[*toolbar*] was much quicker and easier, so that's why I drew more". P7's created story also reflect these results. Figure 5.9 displays how P7 used the brush more in *toolbar* than in *phones*. He first encountered *toolbar* and in this condition he used the brush to a large extent. He encountered *phones* as the third condition and, even though he had had experience with *panels*, his usage of the brush was low. Similar results were visible among other participants, regardless of the order they went through the conditions.



(a) Created story in *toolbar*. High and creative usage of the brush.



(b) Created story in *phones*. Low usage of the brush.

Figure 5.9: A comparison of two created stories in *toolbar* (left) and *phones* (right). It is clearly visible that P7 used the brush more in *toolbar* than in *phones* as other participants also did, confirming the previous results. It is also important to mention that this participant encountered *toolbar* earlier than *phones*

The time of every session was limited. Participants had to spend time in *panels* and *phones* to learn a new interaction paradigm and how to activate / deactivate instruments. Thus, it makes sense that participants drew less in these two conditions since they spent time in other actions.

Similarly, they used the clipboard more often in *toolbar*. We observed that, since they felt more comfortable in this condition, they were willing to create more complicated compositions. These often involved copying and pasting

images inside one another. Participants were also more strict with their performance in this condition, which led to their frequent use of the delete option. In the other two conditions they sometimes grew exasperated with the problems they encountered and would be more tolerant of mistakes.

These changes in instrument usage may also be related to the fact that it was necessary to activate instruments to use them. By needing to do so, participants had to perform more operations to complete an action, which increased friction and may have decreased frequency of use. However, only the difference between the usage of the brush and the clipboard were statistically significant. Hence, this issue was not relevant enough to strongly influence the use of the other instruments.

We are not only interested in the use of individual instruments but on their combinations. For this, we look at the ways participants alternated between them and the order in which they did this.

Alternation between Instruments

We believe that the amount of times participants switch between instruments is a key indicator of behavior patterns shifts. A high amount of switches reflects a pattern centered around objects. This is specially true if switches are performed between the same instruments, like moving and resizing. When a user changes instruments often, it indicates that they are selecting an object, working on it, and then performing other actions on the next one. A low amount of switches, together with prolonged usages of instruments, suggests an instrument centered pattern. When users utilize an instrument for a long period and then switch to another one, it may reflect that they use this instrument on objects sequentially and then they switch instruments to perform another action on a group of objects.

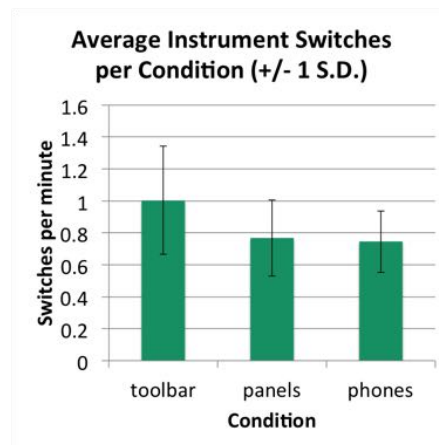


Figure 5.10: The average amount and one standard deviation of switches per minute between one instrument and another. The amount of switches in both *panels* and *phones* is lower than in *toolbar*. This suggests that participants used single instruments for longer periods of times without switching back and forth between them.

We start by looking at the frequency of switches across conditions. Figure 5.10 shows the average amount of switches that occurred in each condition. Participants switched between using different instruments more often in *toolbar* than in *panels* and *phones*. There was a statistically significant difference between the average amount of switches across all conditions ($F(2,38) = 8.005, p < .05$). However, pairwise post-hoc comparisons showed that the differences between *toolbar* and *panels* ($p < .024$) and *toolbar* and *phones* ($p < .011$) were statistically significant, while the difference between *panels* and *phones* was not.

This suggests that participants switched more often between instruments in *toolbar* than in *panels* or *phones*, between which there was a small or no difference. This may be related to the fact that instruments had to be activated and deactivated while in *toolbar* objects had to be selected in order to perform actions on them. There was more effort involved in activating an instrument to use it, which may lead users to try to do it as rarely as possible. A change from object oriented in *toolbar* to action oriented in the other conditions was also spotted by some participants. P13 mentioned that “in [*toolbar* she] moved and painted alternating while in [*panels*] and [*phones* she] first moved all and then painted”.

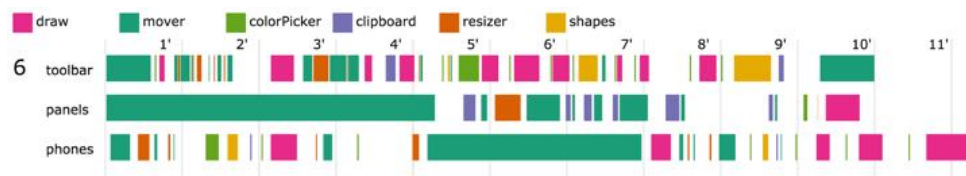


Figure 5.11: Participant 6’s instrument usage in each condition. In *toolbar* switches are more common than in *panels* or *phones*. In the last two conditions a pattern of blocks instead of constant switches is favored.

This behavior is also visible in the scarf plot of actions performed by P6 (Fig. 5.11). He moved and resized in all sessions. In *toolbar* these actions were quickly interchanged with each other, this is visible by the short alternating stripes of the mover and resize instrument in the visualization. In *panels* and *phones* he used each instrument for a longer period without switching so often.

As mentioned above, a high amount of switches would decrease the amount of time participants spent using an instrument before changing to another. This, however, is not as straightforward to compare. As shown in P6’s scarf plot (Fig. 5.11), he used the mover once in each *panels* and *phones* for a long period while all other usages were shorter. If we compare the average and

median lengths of the blocks across conditions, we find that there are differences, although they are not statistically significant. We observe that in both *panels* and *phones* the blocks are longer than in *toolbar*, in accordance to the low vs. high switching patterns, but we cannot confirm this.

Furthermore, when looking at the differences of instruments individually we find a similar pattern for all instruments except the brush. All other instruments show a shorter block length of usage in *toolbar* than in the other two conditions. However, the only of these differences which is statistically significant is the color picker's ($F(2, 38) = 4.651, p < .05$) where the only statistically significant post-hoc pairwise comparison is the one between *toolbar* and *panels*. This supports our conclusion that participants used an instrument for longer periods of time, on different objects, in the UI alternatives.

In general, we observed that participants switched between different instruments more often in *toolbar* than in the UI based conditions. This was linked with a change of behavior in which participants focused more on the actions they performed when these were represented by instruments. It is important to consider that this result might be influenced by the way the interactions in *toolbar* were designed. In this condition, participants had to select an object to perform an action on it. This, and the fact that all other objects would be less visible when one of them was selected, might have shifted participant's focus instead of the presence of instruments.

Order of Instrument Usage

After having analyzed the switching between instruments, it is interesting to look more closely into specifically what instruments participants switched between. This is motivated by observations done on the scarf plots, where there are common switches between certain instruments like brush and color picker as in Figure 5.12.

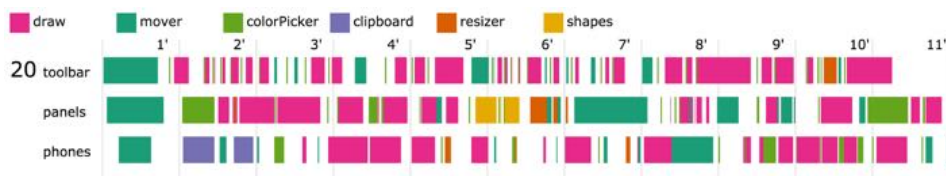


Figure 5.12: Participant 20's instrument usage in each condition. There is a high amount of switches between the brush and the color picker. The frequency of shifting decreases in the second and third row (*toolbar* vs. *panels* & *phones*) favored by prolonged usages of each instrument separately.

Looking at the sequential usage of instrument pairs, we find some interesting patterns. To understand these patterns better we created a simple visualization (Fig. 5.13). It contains a matrix with all instruments as columns and rows. Each cell $C_{i,j}$ in this matrix, where i is the row and j the column, corresponds to the amount of switches from $instrument_i$ to $instrument_j$. The opacity of each cell is directly proportional to the quantity, the lower the amount of such a switch, the lower opacity a cell has. The diagonal of this matrix is empty since we are not interested in participants continuing to use the same instrument here.

We cannot compare all pairs equally, the usage of the mover and the brush was considerably higher compared to the other instruments. We look into pairs along the same row or column, keeping one instrument constant. Participants used the brush and the color picker the most before and after each other. Similarly, participants mostly used the mover and the resize instrument before and after each other. After using the mover, participants used the color picker more often than before. Before using the shapes instrument, participants used the color picker the most and the mover afterwards. Usages of the clipboard were mostly followed by the usage of the mover.

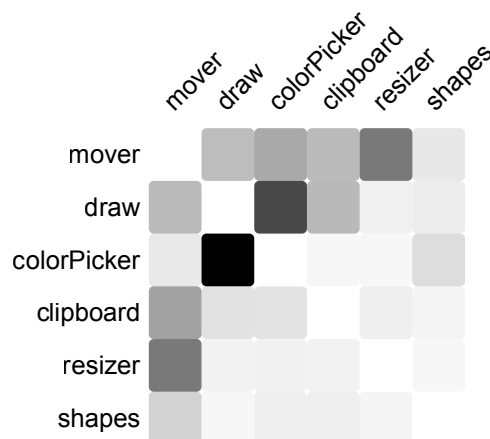


Figure 5.13: Matrix showing average amount of switches between instruments across all conditions. Each cell $C_{i,j}$ in this matrix, where i is the row and j the column, corresponds to the amount of switches from $instrument_i$ to $instrument_j$. The opacity of each cell is directly proportional to the quantity, the lower the amount of such a switch, the lower opacity a cell has.

All these relationships can help us two fold, for further design decisions, as well as comparisons between the three conditions. For further developments of the application, it is important to take these into consideration. For example, the fact that the mover was the tool most used after the clipboard may have an explanation rooted on the design of the instruments. Objects pasted in an object would always be pasted at the top left corner of it. This led to participants pasting and moving the object directly afterwards to the desired position. This shows us how useful this analysis can be. With it, we can observe predominant patterns and analyze whether it is possible to alleviate user's effort.

It is clear that the color picker and the brush have a special relationship, so there should be a way for users to combine them in an easier way to decrease friction. In this same way, further analysis should be performed about the sequential and combined usage of instruments to improve the design of UI applications.

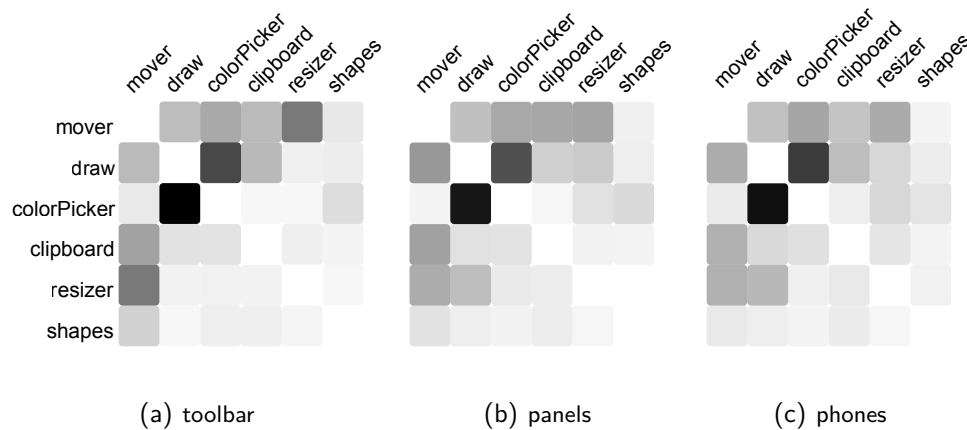


Figure 5.14: Relative amount of switches between pairs of instruments in each of the conditions. Each square corresponds to the amount of times that participants switched from the instrument in that row to the instrument in that column. The darker the square, the higher the amount is. We can observe differences in common pairs of instruments being used in the different conditions. For example, the resize instrument is used with the mover more often in *toolbar* than in the other two conditions.

Now, we look into changes of these behavior patterns across the three conditions. There was a statistically significant difference in the usage of the resize-move combination in *toolbar* (Fig. 5.14). It was higher than in the other two setups ($F(2, 38) = 7.198, p < .05$). The pairwise post-hoc comparison also showed that the usage was different between *toolbar* and *panels* ($p = .034$) and between *toolbar* and *phones* ($p = .026$). We can consider that resizing and moving are too related actions but the fact that these were used more often in only one condition can be explained by another factor. In *toolbar*, both these actions were achieved by gestures, pinching in and out for resizing and touch-drag for moving. Since they did not have to be activated to be used, participants alternated between them very often. Making these actions their own instruments introduced an extra hurdle. They had to be activated and deactivated to be used. This led to a change in behavior pattern, which decreased the alternating usage between them. The usage of these individual instruments did not decrease (Fig. 5.8). Thus, only their combination changed.

Similarly, there was a statistically significant difference in usage of the draw-resize combination ($F(2, 38) = 9.964, p < .05$). Participants used it more often in *panels* and *phones*. Pairwise post-hoc comparisons also showed that the usage was different between *toolbar* and *panels* ($p = .003$) and between *toolbar* and *phones* ($p = .004$). The nature of this change is different to the resize-move shift. The brush was used more in *toolbar* than in the other two conditions, which makes this increase in the other two conditions the more remarkable. This is explained by the fact that the resize instrument was used to change the brush's sample element in the Instrumental Interaction conditions while in *toolbar* it was just a setting in the toolbar.

We found that several instruments have a special relationship that goes beyond conditions. The brush and the color picker are very often used together and the mover was used after the clipboard, for example. In general, this iteration of the DDD consisted of all instruments that were created equally. While this design decision provides complete freedom to the user, we see that there are some pairs of instruments that are used more with each other. This information is very valuable as it helps us understand users' behavior patterns and design for them.

As for differences between the different conditions we found some between *toolbar* and the Instrumental Interaction conditions but none between these last two. The most notable ones are the draw-resize and move-resize combinations. The first combination is mainly related to the design of the DDD. In *toolbar* the brush was changed with the settings while in the other conditions it was done with the resize instrument. The fact that this combination was lower in *toolbar* indicates that participants did use the resize as an instrument to work on the brush as an object. This suggests that they were able to understand a new design paradigm based upon Instrumental Interaction.

The move-resize combination raises the question of what should be an instrument and what should not. When creating a system with instruments, the designer must decide what each instrument does. For example, the clipboard could have been designed as 4 different instruments, copy, paste, cut, and delete. In this case, we merged them together because they are semantically related to each other, users tend to paste directly after they copy and so on. Hence, it made sense to group them to avoid participants having to activate and deactivate different instruments. Since the move-resize combination was used so often in *toolbar*, we might consider that they also are related to each other. This indicates that it is a challenge for designers to decide what actions belong to what instrument. This could be solved by allowing participants to merge and modify instruments beyond their visual

characteristics or by developing a mechanism where instruments could be activated and used more directly

Objectification of Instruments

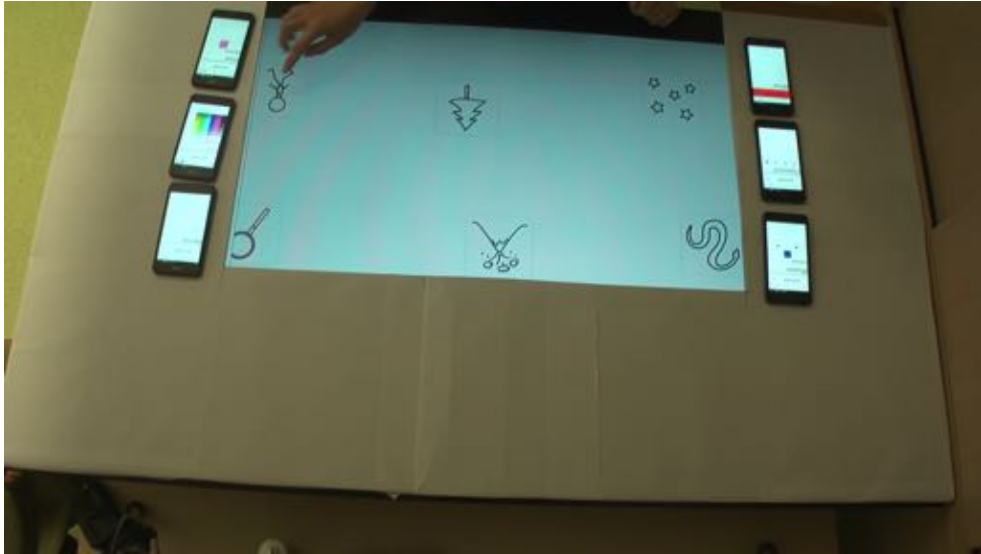
Instruments, from Activity Theory and Instrumental Interaction points of view, can be either artifacts employed to perform actions onto other elements or the object of actions themselves. Here we concentrate on instruments as the objects, and not the artifacts, of an action. We consider this to happen when a participant performs an action onto an instrument, its sample element, or its container (panel or phone). This analysis is crucial to observe if participants used the possibility to treat instruments as objects and whether this treatment is influenced by instruments having a physical presence or not. First, we look at the video encoding data to observe how often instruments were moved, the most straight-forward way of treating them as objects. Then, we use this same data to dive into special usages of instruments upon others. Finally, we look into other aspects, as clashes, activations of instruments, and usage of the sample element to identify similarities and differences between *panels* and *phones*.

Instrument Movements:

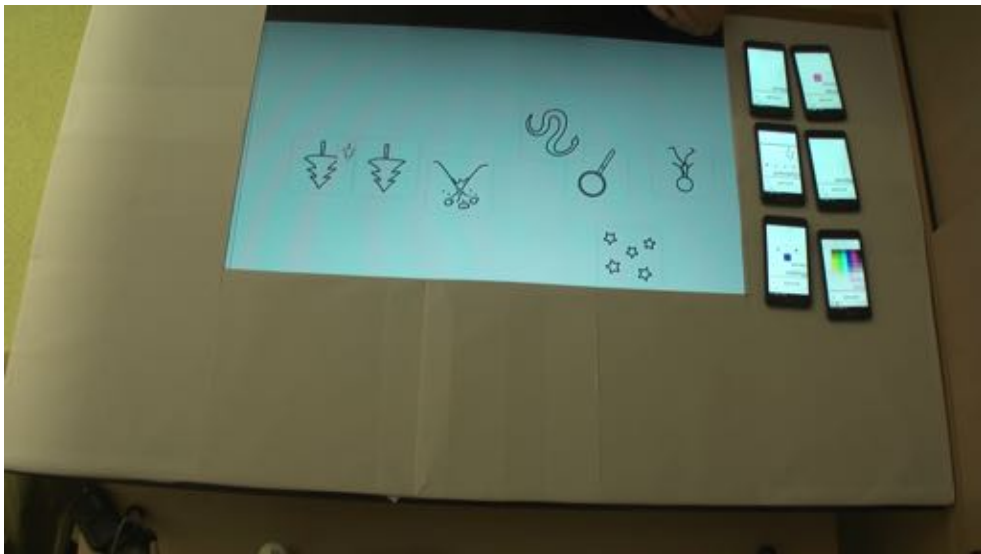
Instruments were moved more in *phones*. 7 participants moved the instruments in *panels* while 9 moved them in *phones*. Of these, 2 moved them in both conditions, which means 14 participants moved the instruments in at least one condition. Among the 12 participants that only moved the instruments in one condition, only 1 of them did so in the first of the Instrumental Interaction conditions. They moved and interacted with instruments more in the second UII session they were presented with.

P1 mentioned, regarding the instruments in *phones*: “I am not that used to this system... it would be a bit challenging to move the instruments [in *panels*] but when it’s a phone, I know I can move a phone around”. Participants moved phones more often than digital panels, they also moved them throughout the session, while they did not the panels. For example, P3 moved the phones into a configuration where 3 phones were on either side of the canvas (Fig. 5.15(a)). After 100 seconds of working in this condition, she realized that it would be better to have all phones on the side of her dominant hand for easier use and a better overview (Fig. 5.15(b)). Even though she had used this second configuration when she worked with *panels* as her first condition, she explored more options with the phones. When asked why they did not move instruments, most participants mentioned that it

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(a) First configuration, phones on either side of the canvas.



(b) Second configuration, phones on one side of the canvas.

Figure 5.15: P3 moved the phones in the beginning of the *phones* condition. She later realized that this organization was not optimal and moved them all to one side to have a better overview.

was because they were not aware they could, regardless of the condition order. However, the fact that they did so more often with the phones than with the panels shows us that the affordance of moving the physical objects was higher.

Special Instrument Usage:

We observed 10 occasions of special usage of instruments, by 5 different participants, as defined in our video encoding (see Subsubsection 5.3.1). 8 of these events occurred in *panels* and 2 in *phones*. These events fell into two categories in equal parts.

The first category corresponded to participants realized by accident that they could color the panels containing the instruments in *panels*. Often, they proceeded to paint other instrument panels and explore the limits of the applications (Fig. 5.16).

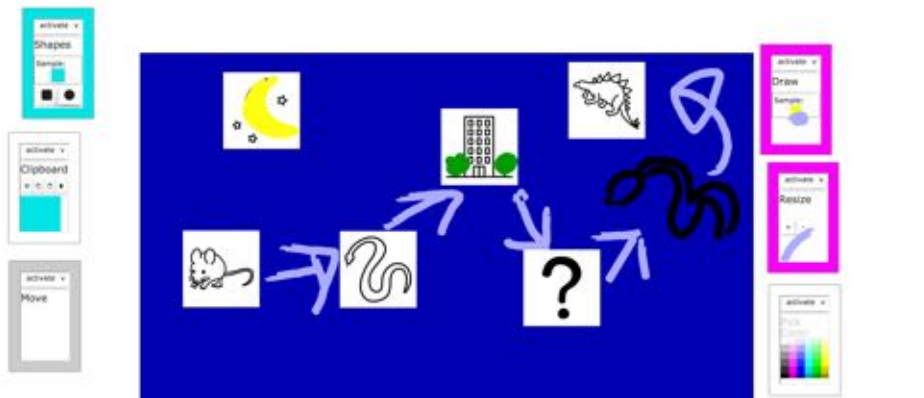


Figure 5.16: P14 explored the possibility of coloring instrument panels in different colors. He also drew strokes on both the draw and resize instruments but did not remove them.

The second category happened when participants would not deactivate the brush when they wanted to change its sample's color or resize it (Fig. 5.16). This led to them creating a stroke inside the brush, which would hinder further interactions. Most participants would ignore this and continue working. Several participants realized that this was the same type of stroke they had interacted with in the canvas and proceeded to use the clipboard to delete it. This showed that they internalized the capabilities of the clipboard instrument and transferred this knowledge to a situation they had not encountered before.

Half of these events were related to coloring the panel containing instruments, something that was not possible in *phones*. Thus, it is complicated to draw conclusions from the fact that most of these events happened in *panels*.

We expected that instruments would be treated as the object of certain actions more in *phones* than in *panels*. However, we did not observe this. We explore this result further with qualitative data at the end of this section.

Instrument Interface Usage:

We proceed to analyze participants' usage of instruments' interfaces. To do this, we observe the activation and deactivation of instruments as well as the usage of the sample element of content creating instruments. We have already seen difference between *toolbar* and the UII conditions. Here, we seek to identify if there are any difference between *panels* and *phones*. In other words, does distributing instruments among different devices have an influence upon users?

Several of the participants mentioned that having physical objects involved having different foci, which raised the difficulty of using the application. We expected that this would lead to participants activating and deactivating less often in *phones* than in *panels*. The difference was small and not statistically significant (Table 5.3).

We looked into the amount of clashes because of the same reason. A clash between two instruments can be defined as an occasion in which both instruments are active. Even though this was a possibility the UII applications offered, participants did not take advantage of it. Whenever this happened, it was because participants forgot to turn one or more instruments off. However, participants could have created new actions by combining instruments, they could have resized images while moving them, for example. From observing the participants, we thought that the introduction of physical devices would increase the amount of clashes between instruments because participants would overlook active instruments. Even though the amount of clashes per minute was close to twice as much in *phones* than in *panels*, this was not a statistically significant difference (Table 5.3).

The frequency in which they interacted with the sample of the brush and the shapes instruments is a factor that may show that participants saw them as objects. We check for differences in the amount of times participants used the color picker and the resize instruments to change samples' color and size,

	panels	phones
Activation	.05 (.13)	.09 (.11)
Clashes	.61 (.24)	.59 (.19)

Table 5.3: Average and standard deviation values of clashes and activations of instruments in *panels* and *phones*. These differences were not statistically significant.

respectively. The color picker was used around twice more often per minute to change the color of a sample element in *phones* ($\mu = 0.076, \sigma = .064$) than in *panels* ($\mu = 0.041, \sigma = .025$). This difference was statistically significant ($F(1, 19) = 4.783, p < .05$). The difference in usage of the resize instrument in the same scenario was negligible and not statistically significant ($\mu = 0.130, \sigma = .134$ in *panels* vs. $\mu = 0.126, \sigma = .169$ in *phones*).

The sample element of the shapes instrument needed not to be change and the brush was usually kept at a relatively constant width. Thus, the resize instrument was not used often to change the size of sample elements in either condition. However, the difference in usage of the color picker is remarkable. It shows that participants recognized the brush and shapes instrument more as objects in *phones* than in *panels*. This makes sense since these are the two content creating instruments. They have characteristics that can be changed with a clear purpose while changes to the other instruments were mostly visual.

Several participants did mention that they (P4) “saw the phones just like the digital instruments” or that there was (P3) “no difference between phones and digital instruments”. We thought that physical instruments would be perceived very differently than their digital counterparts. Participants behavior was influenced by instruments and they did treat instruments as objects in occasions. The phones did not have a strong influence on instrument usage in general, except for the brush and shapes instrument. Participants seemed to have internalized instruments, regardless of their presentation, in the same way.

Even though participants did treat the phones as objects more often than the panels, the contents, the instruments, were not strongly influenced by this. Several mentioned that having the instruments on separate devices in *phones* meant that they had to divide their attention between different focus points (P11: “it was better to have everything on the tabletop”, P10: “I liked [*panels*] more than [*phones*], having everything in one device is better”, P14: “it is

confusing to have so many screens in [*phones*]”). Some of these pointed out that this was an advantage, forcing them to slow down and closely consider the options they had, as well as better understanding that the elements inside the phones are independent instruments with different purposes (P12: “[*phones*] was clearer, I understood that there were different instruments”, P13: “with [*phones*] it makes sense that instruments are in separate devices but in [*panels*] it doesn’t make sense to have this separation, if it’s all in a table”).

Summary

Our first research question was: “How does instrument usage change when introducing instruments and distributing an interface?” We found that there were key changes in the way participants worked between the three conditions. However, most of the differences mentioned in this section are statistically significant between either *panels* and *toolbar* or *phones* and *toolbar*, or both, but not between *panels* and *phones*. Hence, most shifts can be attributed to the substitution of the toolbar with instruments and not to their physical distribution. It seems that instruments were internalized by users regardless of the way they were presented, something which participants also mentioned.

The brush was used more often in *toolbar* than in the other two conditions. This may be attributed to the fact that users felt comfortable in a familiar interface while in the other conditions they had to focus on learning a new design paradigm.

There was a change in participants’ usage patterns of instruments. They transitioned from shifting often between different instruments in *toolbar* to using them for longer periods of time in the Instrumental Interaction conditions. In *panels* and *phones* participants favored a behavior in which they activated an instrument, worked with it on different objects and later switched to another instrument. In *toolbar* participants opted for selecting an object and performing different actions on it. This is specially clear when looking at the combination of mover and resize instrument.

We observed several patterns occurring in the order participants used instruments and tools. The brush and color picker were consistently used together across all conditions. The mover was commonly the instrument used after the clipboard. Other patterns changed between the conditions. The resize instrument and mover were used more often after each other in *toolbar* while the resize instrument was used together with the brush more often in the

other conditions. These are patterns that can help us improve the design of further iterations of the applications.

The treatment of instruments as objects was only slightly influenced by the separation of them into physical devices. Phones were moved more in *phones* than the panels in *panels*. The border of panels was colored while this was not possible in the phones. Participants interacted differently with the different types of instrument containers. This did not influence their use of most instruments. The content creating instruments, brush and shapes, saw an increment in the interaction with their sample element in *phones* compared to *panels*. This indicates that they were viewed as objects that could be changed more often when they were inside individual phones.

Participants reported benefits of the phones. They appreciated their affordability to be moved and the clear separation of components they offered. However, these differences are not directly related to the instruments.

It is important to mention that participants became bolder and more confident with the usage of the systems over time. Since *panels* and *phones* were the same application with two different presentations, they were able to transfer the knowledge obtained while working on one of them to the next one. Following we will explore the ways in which participants learned, specially when encountering a challenging situation as interaction with a new design paradigm.

5.4.3 RQ2: How does Ubiquitous Instrumental Interaction influence the nature and consequences of problems encountered?

In this subsection, we analyze the usage of the applications on the operational level. A breakdown is when a problem in the usage of an application occurs. These problems generally happen when participants have misconceptions of how certain operations work. Breakdowns are key to learning because they offer users an opportunity to step back and try to understand how artifacts function. We focus on understanding the causes and consequences of breakdowns occurring during the experiment in this subsection.

This analysis helps us to identify problematic points that could be improved in the applications. Secondly, we observe how participants use these problems to their advantage to explore and learn about unfamiliar scenarios.

	toolbar	panels	phones
All breakdowns*	12.70 (5.29) ^{1,2}	20.25 (10.09) ¹	18.20 (7.10) ²
Activation breakdowns*	4.30 (3.18) ¹	9.45 (6.66) ¹	6.45 (4.16)

Table 5.4: Means and standard deviation of *all* and *activation* breakdowns per condition. Super scripts display post-hoc pair wise comparisons that are statistically significant across conditions. * shows dimensions which have a statistically significant difference.

Breakdowns

We separated *all* breakdowns into the ones related to *activation* and *other*. In this section, we focus on *all* and *activation* breakdowns. The *activation* breakdowns are the category with the most occurrences, hence we concentrated on understanding them. Table 5.4 shows the averages for *all* and *activation* breakdowns respectively.

There was a statistically significant difference between the amount of breakdowns occurring in *toolbar* and *panels* and *phones* ($F(2, 38) = 6.385, p < .05$). The post-hoc pairwise comparisons between *toolbar* and each of *panels* and *phones* were statistically significant ($p < .05$). The difference between *panels* and *phones* was not.

Most breakdowns were associated with the activating and deactivating of instruments or modes. Since most tools did not have to be activated in *toolbar*, the amount of *activation* breakdowns in this condition was smaller (Table 5.4). This was a statistically significant difference ($F(2, 38) = 6.844, p < .05$). The only statistically significant post-hoc pairwise comparison in *activation* breakdowns was between *toolbar* and *panels*.

These facts are supported by interviews we performed in the end of the session. Users reported that *toolbar* was easier to use, since it resembled applications they are already used to. P15 mentioned “[toolbar] was intuitive because I already know similar things”. The fact that the applications was familiar explains the smaller incidence of problems throughout the session.

We are interested in whether participants learnt during the duration of the sessions or not. It is specially interesting to understand the relationship of breakdowns and learning, since problems that participants encounter can become learning opportunities for them. To do this, we looked at the amount of *all* breakdowns throughout the sessions. The sessions were very short

and the two UII sessions involved the same application in two different presentations. Thus, we looked at the development of breakdown occurrence throughout these two sessions. We compared the amount of breakdowns participants encountered in the first UII session and the second, regardless of the order they went through them.

The average amount of breakdowns in the second UII session the participants encountered was fewer ($\mu = 16.75, \sigma = 5.82$) than in the first one ($\mu = 21.75, \sigma = 10.38$). The difference was statistically significant ($F(1, 19) = 6.665, p < .05$). This indicates that throughout these two sessions participants learnt how to use the applications with fewer problems. We did not find such clear learning signs throughout individual sessions. Hence, we may not be able to solely attribute this to participants learning from the breakdowns they encountered. The extra sample session they had between them might have taught them how to better use the available instruments.

There was a similar relation between the two UII sessions when focusing on their type and not the order. Participants encountered more breakdowns in *panels* ($\mu = 20.25, \sigma = 10.09$) than in *phones* ($\mu = 18.2, \sigma = 7.1052$). The difference was not statistically significant ($F(1, 19) = 6.665, p = .053$). Even though this difference is not statistically significant, it is interesting to note that both *all* and *activation* breakdowns similar in *phones* than in *panels*.

These results could suggest that the phones alleviated the burden that this activation / deactivation mechanism imposed on participants. It is possible that they offer a clear separation of components and their relationship. However, it was clear that participants learned to use the application over time. *Panels* and *phones* only differed in the physicality of the instruments. The amount of problems participants had in the second UII session was fewer. This indicates that the more time they spent with this application the more they mastered it. This is not surprising since breakdowns can offer learning opportunities. When a user encounters a problem, he or she may step back and try to understand the origins of it, leading to learning more about how an application works.

We observed that breakdowns were frustrating for participants, also shown by the results of the TLX and UEQ questionnaires (See Subsection 5.4.3). Breakdowns occurred either because of a mistake or because participants did not understand how an operation could be performed. We saw that when a breakdown was a mistake that the participants knew how to recover from, they recovered quickly. This was specially visible in *toolbar*, where participants occasionally wanted to move an object while on drawing mode.

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When this happened, they would immediately exit drawing mode without switching focus. This way of recovering from breakdowns indicated to us that participants had an understanding of how the application worked.



Figure 5.17: P5 had problems grasping the concept of activation and deactivation. Here we show her final configuration of *panels*, where 4 of the instruments are active at once. Even though she used *phones* before she did not learn from the breakdowns she encountered and had problems throughout both conditions.

In *panels* and *phones* most breakdowns were approached from a different angle because they were mostly rooted in misunderstandings. It was more common for users to fall into either random behavior or reflection. These behavior patterns were best observed with the activation of instruments, since this was a problematic area. Several participants mentioned that it was “annoying to activate and deactivate” (P10, P11, P15, P19, P20) and P5 mentioned “I didn’t understand in the beginning how activating and deactivating works”. Certain participants would randomly activate and deactivate instruments in what seemed to be trial and error. These participants continued working similarly throughout the entirety of the session. For example, we observed such behavior from P5. She went first through *phones* and then *panels*. Even though she had these two sessions to understand the activation and deactivation of instruments, she continued to have issues in the end of her second UII condition (Fig. 5.17). Participants that stepped back and sought to understand the root of the problem, encountered fewer problems later on. This indicates that participants learned how to work with this new design paradigm in the short time of the study.

Summary

In this subsection, we looked into problems encountered while fulfilling the tasks. These breakdowns can present learning opportunities to users. The way that users approach these breakdowns may also show the level of understanding they have of how an application works. During our study, participants encountered fewer problems in *toolbar* than in the other two conditions. We observed that these problems decreased with time as participants used the Instrumental Interaction based applications. We argue that the high incidence of breakdowns in the first sessions together with the lower incidence in the second is a clear sign that participants were able to quickly learn to use these applications with a new interaction paradigm.

5.4.4 RQ3: How does Ubiquitous Instrumental Interaction influence user experience and task load?

Finally, after having looked into the problems participants encountered we analyze their reports of task load and user experience. Even though we observed them and asked them questions in the end of the study, we used two questionnaires to obtain quantitative information in this area.

The NASA-TLX questionnaire involves participants reporting their own subjective opinion about the load exerted on them by each of the tasks. This load is separated into 6 different scales which they used to rate the tasks: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration.

The User Experience Questionnaire (UEQ) also provides different scales to participants, which they used to characterize applications. For example, a scale prompted the participant to rate an application between “attractive” and “unattractive”. There are 29 scales which fall into 6 categories: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.

These questionnaires are valuable. They minimize biases that examiners could bring into analysis or that could influence participants into answering questions. They also provide a quantitative approach to areas that are hard to quantify. Since they are widely used, they also help us analyze our results in a broader context.

	toolbar	panels	phones
Total	28.63 (21.99)*	37.79 (13.68)	37.66 (16.67)*
Mental Demand	34.50 (21.99)	45.00 (22.18)	48.50 (22.13)
Physical Demand	25.50 (17.91)*	40.50 (24.06)*	32.50 (20.29)
Performance	20.79 (21.10)*	33.50 (21.53)	39.65 (29.40)*
Effort	32.00 (19.70)*	44.25 (20.73)*	37.50 (21.67)

Table 5.5: Average value of the total average value and statistically significant sub-scales of the TLX questionnaire. The standard deviation values are in parenthesis. * indicate post-hoc pairwise statistically significant differences between conditions.

Task Load

We use the NASA-TLX to explore participants' subjective ratings of the load they felt in each of the conditions. Participants rated each condition for each sub-scale on a scale from 0 to 100. We calculate the average value of each sub-scale, as well as the total task load which is an average of all the sub-scales. Table 5.5 displays all the sub-scales that showed a statistically significant difference across conditions.

The total task load average proved to have a statistically significant difference ($F(2,38) = 4.774, p < .05$) between the conditions, while the post-hoc pairwise comparisons between conditions did not.

The following sub-scales also had statistically significant differences across conditions: mental demand ($F(2,38) = 4.372, p < .05$), physical demand ($F(2,38) = 4.469, p < .05$), self performance estimation ($F(2,38) = 6.390, p < .05$) and effort ($F(2,38) = 4.786, p < .05$). Some post-hoc pairwise comparisons proved to have statistically significant differences. Perceived effort and physical demand between *toolbar* and *panels* were statistically significant differences, they were both lower in *toolbar*. Total task load average and self assessment of performance between *toolbar* and *phones* were also statistically significant differences, with *toolbar* being lower.

Participants were familiar with similar designs to *toolbar*, while *panels* and *phones* introduced a new design paradigm. Thus, we consider that the differences between these values is lower than expected.

Both the physical demand and effort showed a statistically significant difference between *toolbar* and *panels*. These measures increased by changing the toolbar into instruments. However, there was no statistically significant difference between *panels* and *phones*. This may suggest that the introduction of physical devices to contain instruments alleviated the burden associated with switching to a new paradigm.

As we discussed in the previous subsections, participants moved the physical instruments more often than the panels. Several participants mentioned that this separation helped them better understand the instruments. Participant 13 mentioned in the interview that “[*panels*] is more confusing than [*phones*] because in [*phones*] it was also separated and clearer” and participant 12 said that “[*phones*] was clearer, I understood that there were different instruments”. These comments suggest that the physical separation of instruments aids in understanding that they are separate tools.

Some participants did mention that they found it better to only have one device (P14 “having different devices was confusing”). In general we could not find any statistically significant difference between *panels* and *phones* and participants’ opinions seemed to vary according to personal preferences. We proceed to inspect differences in their reported user experience across the different conditions.

User Experience

The UEQ helps us understand the experience participants had in each of the conditions. Each question in this questionnaire belongs to one of 6 sub-scales (attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty) of which 3 proved to have a statistically significant differences in our experiment (Table 5.6). Attractiveness ($F(2, 38) = 3.765, p < .05$), perspicuity ($F(2, 38) = 5.261, p < .05$) and efficiency ($F(2, 38) = 5.888, p < .05$) were all rated to be higher in *toolbar* than in the other two conditions. Pair-wise post-hoc comparisons were statistically significant for efficiency and perspicuity between *toolbar* and *panels*.

The creators of the UEQ offer values for comparison with an established benchmark of 9905 participants and 246 studies (Schrepp et al., 2013). Of this data, they separated each sub-scale into certain percentile groups into excellent (90-100), good (75-90), above average (50-75), below average (25-50)

	toolbar	panels	phones
Attractiveness	1.43 (0.96)	0.89 (0.86)	0.82 (1.32)
Perspicuity	1.94 (0.98)*	1.10 (0.90)*	1.15 (1.17)
Efficiency	1.16 (0.99)*	0.36 (1.04)*	0.46 (1.28)

Table 5.6: Average values of each UEQ sub-dimension with a statistically significant difference. The standard deviation values are in parenthesis. All dimensions have a statistically significant difference. * indicate post-hoc pairwise statistically significant differences between conditions. The colors correspond to the score a condition had in a certain sub-scale with respect to the benchmark. Dark green corresponds to excellent, green to above average, red to below average and dark red to bad.

and bad (0-25) (Table 5.6).

The results for the 3 sub-scales, attractiveness, perspicuity, and efficiency, that showed statistically significant differences were lower for both *panels* and *phones* than in *toolbar* but still above 0. For attractiveness and efficiency, even though the values were positive, they still were below the average benchmark. Compared to the benchmark there is still room for improvement. It is interesting to note that, the post-hoc comparison of the efficiency value between *phones* and *panels* was not statistically significant. In Subsubsection 5.4.2 we see that participants had contrasting opinions about having digital or physical instruments. However, we expected that since participants moved phones more often and configured the workspace to their preferences more in this condition, they would have perceived it as more efficient.

The reported perspicuity of each application, the ease to understand it, was not only positive across all applications but ranked as above average in comparison with the benchmark. This shows that participants understood the new interaction paradigm they were presented with.

The efficiency in *panels* was statistically significantly lower than in *toolbar* and it was considered bad, compared to the benchmark, in both *phones* and *panels*. Participants raised their concerns about the inability to work fast in both *panels* and *phones* which may be related to this sub-scale. Participant 10 said that he “liked [*toolbar*] the most and found it easier and faster [to use]”. Even though this was the case several participants mentioned that having instruments helped them structure their thoughts and actions and thus worked in a more organized. Participant 13 mentioned she could

“structure thoughts better in [*panels*] and [*phones*] because [I] would decide to move first and then resize, for example”. We can argue that a reduction in efficiency may not necessarily be a drawback, if it brings with it new possibilities to the user. Specially if participants quickly learn how to use the applications, as shown in the previous subsection.

Summary

In this subsection, we explored the data related to the activities performed by participants. We saw that regardless of the previous experience participants had with WIMP user interfaces, they understood the new interfaces based on Instrumental Interaction. Not only did they also understand how to work with these applications, but the data and participants reported valuable information about how the presence of physical devices influenced these activities. Having instruments inside individual phones seems to reduce the physical demand and effort imposed on users. Instruments may also help them organize their thoughts and interactions.

5.4.5 Conclusion

In this section, we observed the influence UII has upon creative sensemaking. We used the data we gathered from the conduction of a task-based counter-balanced within-subject study. The data came from varied sources like data logs, video data, interviews, questionnaires, generated story, and observations. We were interested in answering our research question: “How does Ubiquitous Instrumental Interaction influence users’ behavior in creative sensemaking tasks?”. We broke down our research question into smaller ones which we used to structure our analysis.

First, we started off by looking at the demographic data. This showed that all participants had experience with touch devices and had no problems with interacting with our applications. There were also no significant outliers that would have had to be considered. We then continued into answering each of the research questions.

The first research question (**RQ1**) involved understanding changes in behavior when using UII based applications. We focused on four dependent variables: instrument usage length, alternation, order, and objectification. We found that most differences in what participants did were between *toolbar* and the other two applications. There were only small changes in instrument usage between *panels* and *phones*.

Participants switched their behavior when presented with applications based on UII. Since instruments are the reification of actions into objects they can also be treated as such. Hence, because they can be treated as objects they can be given more focus than actions that are not represented in the user interface. Being able to focus on actions in this way led to participants doing so. In the Instrumental Interaction conditions they would concentrate on actions instead of objects in the canvas. They chose an instrument, the mover for example, and used it on different objects before switching to another action. In *toolbar*, however, participants selected objects and performed different actions on it, like moving and resizing, before switching to the next object.

RQ2 looked at problems, breakdowns, participants encountered, their origin and their consequences. We do not see these breakdowns just as problems with the interfaces but as learning opportunities. It was clear that this was the case when dealing with the UII applications. Even though participants had issues getting used to these, they had fewer problems as they used them more. These breakdowns offered them opportunities to step back and analyze their origins in order to overcome them. Furthermore, participants that did this, showed an understanding of the applications, exploring the limits and internalizing the concepts faster. These participants showed that Instrumental Interaction may be hard for users to understand in the beginning but offers a vast amount of possibilities and power in the combination of instruments.

We finally looked into the user experience and task load that participants reported, to answer **RQ3** Here, we saw that many of the measures from the UEQ and NASA-TLX questionnaire showed no statistically significant differences between the conditions. This is surprising since we introduced a novel design paradigm and expected these difference to be more notable. There were several measures across both the NASA-TLX and UEQ that were significant, always showing a larger difference between *toolbar* and the other two conditions than between these. More interestingly, the results for several dimensions, task load, physical demand, effort, perspicuity, and efficiency, was reported to be higher in *phones* than in *panels*. Even though not all these differences were statistically significant, they show that physical instruments diminish some issues that are introduced by presenting participants with a novel design paradigm.

With our analysis we showed that the behavior patterns participants employed to fulfill the tasks were indeed influenced by Ubiquitous Instrumental Interaction. Moreover, even after having had problems with the UII ap-

plications, participants learned quickly and reported to have enjoyed using these systems. In the next chapter we use these results to propose improvements to the DDD. We will also point out considerations that need to be taken when designing UII systems.

Conclusion

In the beginning of this thesis we explained why having Distributed User Interfaces (DUI) is desirable. We proceeded to introduce Instrumental Interaction and Ubiquitous Instrumental Interaction (UII). We used these models to create three applications which we used to conduct a study.

This study allowed us to investigate the effects of distributing physical instruments on users' behavior. The applications we developed were crucial for this purpose. The first was a DUI across different devices based on UII (*phones*). The second was this same application, but with all components together in one device (*panels*). This helps us compare and contrast just the physical distribution of the instruments. The third was a simple WIMP related interface with a toolbar above a document (*toolbar*). This application could perform the same actions as the other two. It helped us understand the differences in users' behavior in creative sensemaking when changing such an interface for instruments.

We conducted a study comparing how 20 participants interacted with these three different applications. In the previous chapter we discussed the valuable information we obtained about the difference in usage patterns of instruments. These results and their corresponding discussion informed us about limitations in our application and our evaluation approach. We use these to elaborate on considerations developers should take when creating such application. They also showed us how UII is a suitable framework for distributing user interfaces in collaborative scenarios.

6.1 Limitations

In this section, we elaborate on the limitations that we observed while and after conducting our study. These fall into two categories, the ones related to the applications and the ones related to the evaluation. It is important to point them out for further work.

6.1.1 Distributed Digital Desk

The Distributed Digital Desk allowed us to quickly and easily set up three different applications. We used the already existing instruments to create two different versions of a DUI based on UII. The same functionality that powered these instruments let us create a toolbar application resembling these applications. The fact that we were able to do this shows that UII is very well suited for creating component based applications. Furthermore, we experienced how robust such an application is when distributed among different devices. With no more necessary setup we could open different components in individual devices which communicated with each other. Even though the study was successful, the instruments of the DDD can still be improved.

It was not possible for us to include an undo functionality into the Distributed Digital Desk (DDD), the system we used to develop our applications. We considered this to be acceptable for our study, even though this would have not been the case with a commercial system. Participants were usually able to revert their actions by using other instruments and tools, specially the clipboard for copying and deleting. Even though this was the case, it is possible that the breakdowns mentioned in the previous chapter could have been alleviated by the presence of such functionality. However, since this was consistent across all conditions it influenced all results equally, allowing for comparisons.

Similarly, pasting an object inside a container placed the object on the top right of the container. Participants mentioned that they expected the object to be pasted where they indicating and not on the top right. This raised confusion among several of them but once they understood this they proceeded to move the objects to the desired position without problems.

The instruments in the DDD are differentiated by their name while in the *toolbar* most of them had an icon associated with them. This was a difference that emerged from the design of the instruments. The design of instruments should be more in accordance to common commercial interfaces in the future. However, this problem was alleviated by the small amount of instru-

ments and all sub-instruments in an instrument had icons symbolizing what they did.

6.1.2 Evaluation

We designed the study tasks to resemble the “Story Cubes” game. We obtained the images on the sides of the dice of one of the versions of the game. Later, we provided participants with 6 random different images for each condition. A random selection of images from the whole set does not reflect the way the game is supposed to be played. Images in one die are usually related to each other, different faces or animals for example. By choosing random ones these images sometimes belonged to the same die. Participants were always able to find a story connecting these images but this fact may have made it harder in some cases.

Another issue was related to the amount of participants. We had 3 different conditions. To counter balance we conducted the experiment with all 6 different orders of these conditions. However, we recruited 20 participants, leading us to repeat some orders. We considered that having two repeated combinations was not a problem with this amount of participants and conditions. We checked certain statistics in the results with 18 of the participants equally distributed among the 6 conditions and observed no difference in the emerging patterns.

6.2 Future Work

We believe that the distribution of user interfaces, both for individual and collaborative work, and the use of Instrumental Interaction to do so are topics that should be researched further. In this section, we outline certain considerations that should be taken when designing and developing this type of interfaces as well as ways these can be used in collaborative scenarios.

6.2.1 Design Considerations

After having developed the applications and conducted the studies we found that it is not only hard for participants to be confronted with a new design paradigm, but it is also a challenge for developers. We had to change our mindset and reorganize the design and development of the application to accommodate this new configuration. There are several problems we encountered, some solved and some not, that could be avoided in future similar projects.

Instrument Usage

How do instruments interact with each other? In our design we opted to have an activation / deactivation button for each instrument. This was the most problematic interactions participants had to get used to. It took them time to understand it and it introduced an extra operation they had to perform when wanting to use an instrument. The problem may not have been the extra operation but its nature. The presence of the button involved participants having to press a relatively small area on the screen.

The act of activating different instruments allowed participants to combine instruments as desired. However, this functionality was seldom used. Even if participants used certain instruments often on each other, changing the color of the brush with the color picker for example. Because of this, we propose several ways in which the usage of instruments can be improved in the future. Some involve the combination of instruments while others do not.

The most direct way to solve this issue would be to implicitly activate the last instrument that has been interacted with. We observed that several participants expected this would be the way instruments would be activated. This would lead to a simple interaction but would not allow for parallel activation of instruments. Since participants did not take advantage of this possibility, maybe this interaction would solve the problem.

An instrument could be considered active whenever it is grabbed or placed near the user. This may exert a higher physical demand onto the user but it resembles the way physical tools are used in the analogue world. We must grab a pen or a hammer to be able to use it. If instruments are on different devices users could bring all the ones they want to activate towards them to do so. This interaction must be implemented carefully as it could lead to false positives.

A device, or an area in a workspace, could be assigned to be in charge of the activation of instruments. We observed that participants had no problems with switching between modes in *toolbar*. Similar to this toolbar the user could have a hub with buttons for all instruments where they can decide to which one(s) to use. This, however, becomes a problem when there is a large amount of instruments or when there are several instances of the same one. It provides an easy overview of what is active but it also separates the actual instrument from its activation functionality.

A way to also alleviate the activation / deactivation problem is to combine instruments. In this way, users would not have to use the color picker on the brush every time they want to change its color. This could be achieved by placing a new color picker inside the brush which only is responsible for this objects color. This leads us to another factor that has to be considered.

Instrument Definitions

It is important to carefully decide what functionality belongs to what instrument. Having each single functionality as a separate instrument will lead to an unmanageable amount of them. Our clipboard was conformed of 4 semantically similar operations, cut, copy, paste and delete. This was a successful separation of instruments. However, we observed that the move and resize instruments were used very often with each other. A question for future work is whether such instruments should have been merged into one to let users perform these actions easier.

There are other factors related to the amount of instruments in an application. A large amount of instruments presented at once can be overwhelming to a user. Specially, if each instrument is in a separate device. Several participants already mentioned that 6 different devices was too much. Also, considering that people usually do not own that many devices there must be a way to reduce this. The DDD allows for the creation of toolboxes that contain several instruments in one device. Unfortunately we were not able to evaluate this functionality, since there is no analogous way to do this in simple WIMP related interfaces. Whether or not such toolbars would be a suitable solution to this problem is an interesting question yet to be answered.

The developers of VIGO mentioned that the increase of instruments, increases the complexity of an application exponentially (Klokmoose and Beaudouin-Lafon, 2009). Even though we did not encounter this problem in the development of the DDD, when preparing the study, it became clear that this is the case. The DDD does not have governors as defined in VIGO. This means that any interaction is valid, even interactions that may reach to undesirable states. Even though this is the embodiment of the flexibility and power Instrumental Interaction has to offer, it is not possible to conduct a study with such an application, specially with no undo functionality. To improve this, we had to put restrictions in place. Since the amount of time we had to do this was limited, we were not able to introduce governors into our design and had to limit what each instrument could do from within. This quickly raised the complexity of the application to a point where it be-

came very hard to work with. We expect that having governors in the design from the beginning would alleviate this problem but it would still be a large amount of elements to keep track of.

Designing such a complex application results in a balancing act between decisions made for the user and freedom left to the user. Design decisions reduce complexity of the system but they may also reduce the possibilities left to the user. However, leaving all decisions up to the user is overwhelming when first using a system. More research should be done on the ways to present instruments based on Instrumental Interaction in applications.

The work we did in this thesis successfully showed relationships between certain instruments. This can be used as the baseline for further studies that would help us understand how to define instruments.

It may also be interesting to use the measurements presented in Beaudouin-Lafon's introduction of Instrumental Interaction Beaudouin-Lafon (2000). He outlines three measures that can help categorize instruments from a theoretical point of view. Such an analysis, together with our empirical approach, could lead to a better understanding of what constitutes a successful instrument.

In our experiment we saw how it may be desirable to distribute these instruments among physical devices. It allowed participants to grasp the new design paradigm faster and more efficiently. This phenomenon is not only well suited for individual work but, as we saw in the related work, lends itself to collaborative scenarios. Following are several interesting research questions that could evolve this research area.

6.2.2 Collaborative Usage

With this thesis we showed that UII may be the answer to achieving DUIs. Applications that are designed and made up from individual components are very easily distributed across different devices. There is no need to struggle with coordination among the different parts of the application because these components were designed to work with each other while being individual entities. Having interfaces that are distributed and component based applications is well suited for collaboration. Users can lend each other devices and components to build individual applications. But they can also combine their artifacts and instruments to create more powerful interfaces in which they work together.

In this last subsection, we discuss interaction techniques that would need to be established for such applications. We also raise questions that could be investigated with these applications.

The crucial question is how to achieve proper interactions in such a scenario. When collaborating it is not only important to know which instrument is active but who is using it. When a user interacts with an object, she expects the performed operation to be the one corresponding to the instrument she is currently using and not that of another user. Hence, the system powering these applications needs to be able to identify what actions are associated with what instruments and user. Here we discuss several ways to achieve this interaction.

In the physical realm, operations are done unto a document through the instrument that a user is holding in her hand. There is no ambiguity in such situations. To achieve an analogous interaction, we could design it to involve grabbing the device containing the instrument and using it to perform the action. Ideally each instrument would have a physical representation. A drawing tool could be represented by a brush and so on. However, this is not feasible in most scenarios since we expect users only one touch devices such as phones and tablets. In this case, devices could have a bumper that allows for its corner to interact with other touch capable devices. Hence, if each devices has a unique identifier, there would be no problems knowing what action is being performed. This, however, is not suitable for certain interactions, like multi-touch gestures. It also introduces extra hardware which may not be desirable.

Another way to identify users' interactions also involves extra hardware, but one that may become ubiquitous in the future. If users have a smart watch, which they use on their dominant hand, they could pair it up with the system. The system could then recognize movements of this watch attribute them to individual users. If every user would have a smart watch this would be a minimally invasive and efficient solution.

After having overcome this problem, this type of interaction could be used to augment current possibilities in collaborative scenarios. Not only in co-located situations but elsewhere as well. Future research could further understand the effects of this type of applications on collaborative spaces. Also, it may be interesting to investigate whether such interactions, distributed across space, would also be possible. There is a rising amount of people that work remotely. Hence, collaboration does not only have to let them work together in the same room but also potentially across continents. Having an

6. CONCLUSION

application with components distributed with UII could help in such situations.

In this thesis, we presented a novel interaction paradigm. We observed in our study that participants were excited to work with applications based on UII and understood this model quickly. In this chapter, we presented several exciting questions and scenarios in which such applications could be used. We look forward to experiencing where this fast paced research area will expand to.

Appendix A

Appendix

A.1 Consentment Form

ID: _____

Einverständniserklärung

Informationen zur Studienleitung _____

Studienleiter: Carmela Acevedo, Ulrike Pfeil, Johannes Zagermann

Institution: Arbeitsgruppe Mensch-Computer Interaktion, Universität Konstanz

Projekt: TRR161_Co1_Quantifying Interaction

Studienablauf _____

Wir möchten Sie nochmals auf folgende Punkte zu unserem Studienablauf aufmerksam machen: Sie können die Studie jederzeit abbrechen! Sollten Sie eine Pause benötigen, scheuen Sie sich nicht, uns dies mitzuteilen. Wenn Sie Fragen zum generellen Ablauf oder zum System haben, können Sie diese jederzeit stellen. Bitte haben Sie jedoch Verständnis dafür, dass wir aufgabenspezifische Fragen erst nach der Studie beantworten können, um eine Verzerrung der Daten zu verhindern.

Erklärung _____

Über das Ziel, den Inhalt und die Dauer der Studie wurde ich informiert. Im Rahmen dieser Studie werden durch Fragebögen personenbezogene Daten erhoben. Zusätzlich wird die Studie auf Video aufgenommen und es werden Nutzungsdaten erfasst.

Hiermit bin ich darüber aufgeklärt, dass diese Daten anonymisiert analysiert werden, vertraulich behandelt werden und nicht an Dritte weitergegeben werden. Video- und Nutzungsdaten werden ausschließlich für die Auswertung zu genanntem Zweck verwendet und – mit meinem Einverständnis – für interne Präsentationszwecke genutzt.

Hiermit erkläre ich mich mit den oben genannten Punkten einverstanden:

(Name)

(Ort, Datum)

(Unterschrift)

Hiermit verpflichtet sich die Untersuchungsleitung, die Videoaufzeichnung sowie sämtliche sonstigen gewonnenen Daten lediglich zu Auswertungszwecken im Rahmen dieser Untersuchung zu verwenden:

(Name)

(Ort, Datum)

(Unterschrift)

A.2 Questionnaire

ID: _____

Fragebogen

Herzlichen Dank, dass Sie sich bereit erklärt haben an dieser Untersuchung teilzunehmen. Bevor wir anfangen, benötigen wir von Ihnen noch einige Angaben zu Ihrer Person und Ihrer bisherigen Erfahrung mit Computern. Wir möchten Ihnen hiermit noch einmal mitteilen, dass alle Daten vertraulich behandelt werden.

Personenbezogene Daten _____

Alter: _____

Geschlecht: männlich weiblich

Schulbildung:

Hauptschule Realschule Gymnasium Sonstiges: _____

Momentane Tätigkeit/ Beruf: _____

Benutzen Sie eine Sehhilfe? ja nein

Falls ja, tragen Sie überwiegend... eine Brille Kontaktlinsen beides

Falls ja, welche Art von Sehschwäche haben Sie?

Kurzsichtigkeit – wie stark? _____

Weitsichtigkeit – wie stark? _____

Sonstiges: _____

Sind Sie...?

Linkshänder Rechtshänder Beides Weiß nicht

Computernutzung _____

Seit wie viel Jahren benutzen Sie einen Computer? _____

Wie viele Stunden verbringen Sie täglich an Ihrem Computer?

- Bis zu 1 Stunde
- Mehr als 1 Stunde, bis zu 2 Stunden
- Mehr als 2 Stunden, bis zu 3 Stunden
- Mehr als 3 Stunden

Berührungsempfindliche Geräte _____

Haben Sie Erfahrung mit der Nutzung berührungsempfindlicher Geräte (z.B. Apple iPad, Samsung Galaxy Pad)?

- Ja
- Nein

Falls ja, ...

...welche berührungsempfindlichen Eingabegeräte haben Sie bereits selbst genutzt?

...bei welchen Gelegenheiten und/oder zu welchem Zweck nutzen Sie diese Geräte?

....wie oft nutzen Sie berührungsempfindliche Geräte?

- Weniger als 1 mal die Woche
- 2-3 mal die Woche
- 3-6 mal die Woche
- täglich
- mehrmals täglich

A.3 TLX

ID: _____

Fragebogen

Beanspruchung System _____

Geben Sie bitte an, wie hoch die Beanspruchung in den einzelnen Dimensionen war. Markieren Sie dazu auf den folgenden Skalen bitte, in welchem Maße Sie sich in den sechs genannten Dimensionen von der Aufgabe beansprucht oder gefordert gesehen haben:

Beispiel:



Geistige Anforderungen

Wie viel geistige Anstrengung war bei der Informationsaufnahme und bei der Informationsverarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen ...)? Empfinden Sie die Aufgabe als leicht oder anspruchsvoll, einfach oder komplex, erfordert sie hohe Genauigkeit oder ist sie fehlertolerant?



Körperliche Anforderungen

Wie viel körperliche Aktivität war erforderlich (z.B. ziehen, drücken, drehen, steuern, aktivieren...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholend oder mühselig?



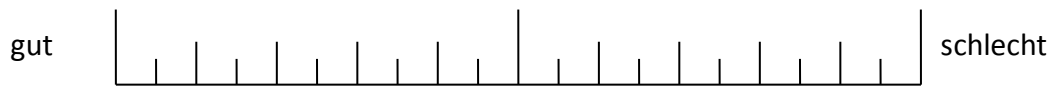
Zeitliche Anforderungen

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?



Ausführung der Aufgaben

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter oder Ihnen selbst gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?



Anstrengung

Wie hart mussten Sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?



Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert fühlten Sie sich während der Aufgabe?



A.4 UEQ

ID: _____

Bitte geben Sie Ihre Beurteilung ab.

	1	2	3	4	5	6	7		
unerfreulich	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	erfreulich	1
unverständlich	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	verständlich	2
kreativ	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	phantasielos	3
leicht zu lernen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	schwer zu lernen	4
erfrischend	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	einschläfernd	5
langweilig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	spannend	6
uninteressant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	interessant	7
unberechenbar	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	voraussagbar	8
schnell	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	langsam	9
neu	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	alt	10
unbedienbar	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	bedienbar	11
gut	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	schlecht	12
kompliziert	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	einfach	13
abstoßend	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	anziehend	14
veraltet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	modern	15
unangenehm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	angenehm	16
vorhersagbar	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	unvorhersagbar	17
abwechslungsreich	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	eintönig	18
zuverlässig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	unzuverlässig	19
ineffizient	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	effizient	20
übersichtlich	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	verwirrend	21
stockend	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	flüssig	22
aufgeräumt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	überladen	23
schön	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	hässlich	24
sympathisch	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	unsympathisch	25
unauffällig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	auffällig	26

A.5 Interview

- Please describe the activities you needed to solve the task. (for each condition!) (what kind of activities? Sequence of activities? Most important activity? Unnecessary activity?)
- Please describe the influence of the different conditions on the development and results of your stories.
- What do you think? Which condition supported you the most in fulfilling your task? Why? (Any problems?)
- Which condition do you prefer? Why? Rank them.
- Name one thing you liked and one thing you did not like for each condition.
- How do you feel about using multiple devices at the same time?

A.6 Flyer

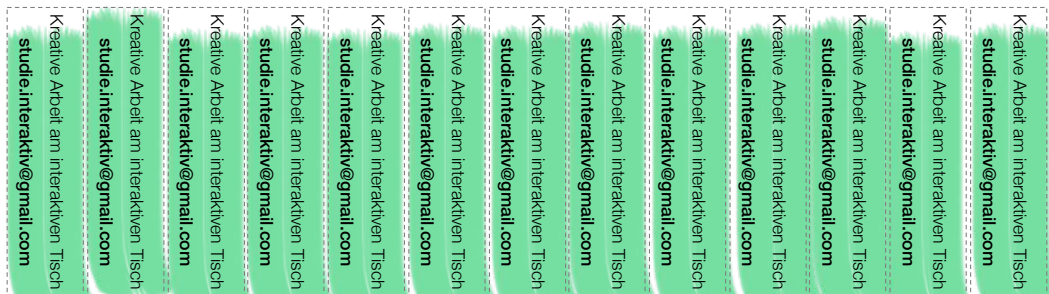
STUDIERENDE GESUCHT!

Kreative Arbeit am interaktiven Tisch

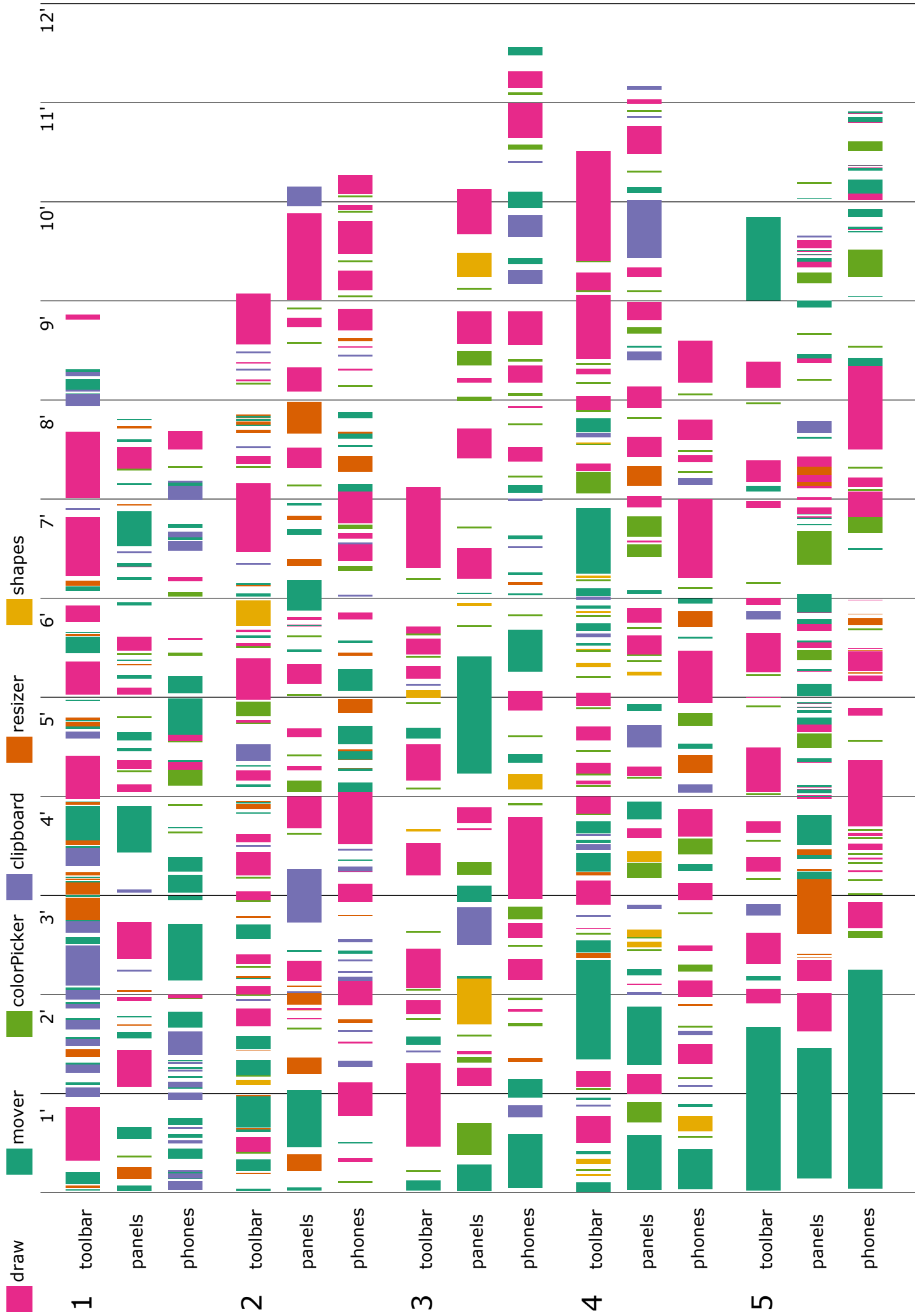
Im Rahmen eines Forschungsprojektes untersuchen wir mit Hilfe eines **interaktiven Tisches und mobiler Smartphones** verschiedene Interaktionskonzepte für kreative Arbeit. Im Rahmen der Studie bekommen Sie Aufgaben, die mittels dieser innovativen Tools gelöst werden. Die Studie dauert insgesamt etwa **90 Minuten** und wird mit **12 Euro** entschädigt.

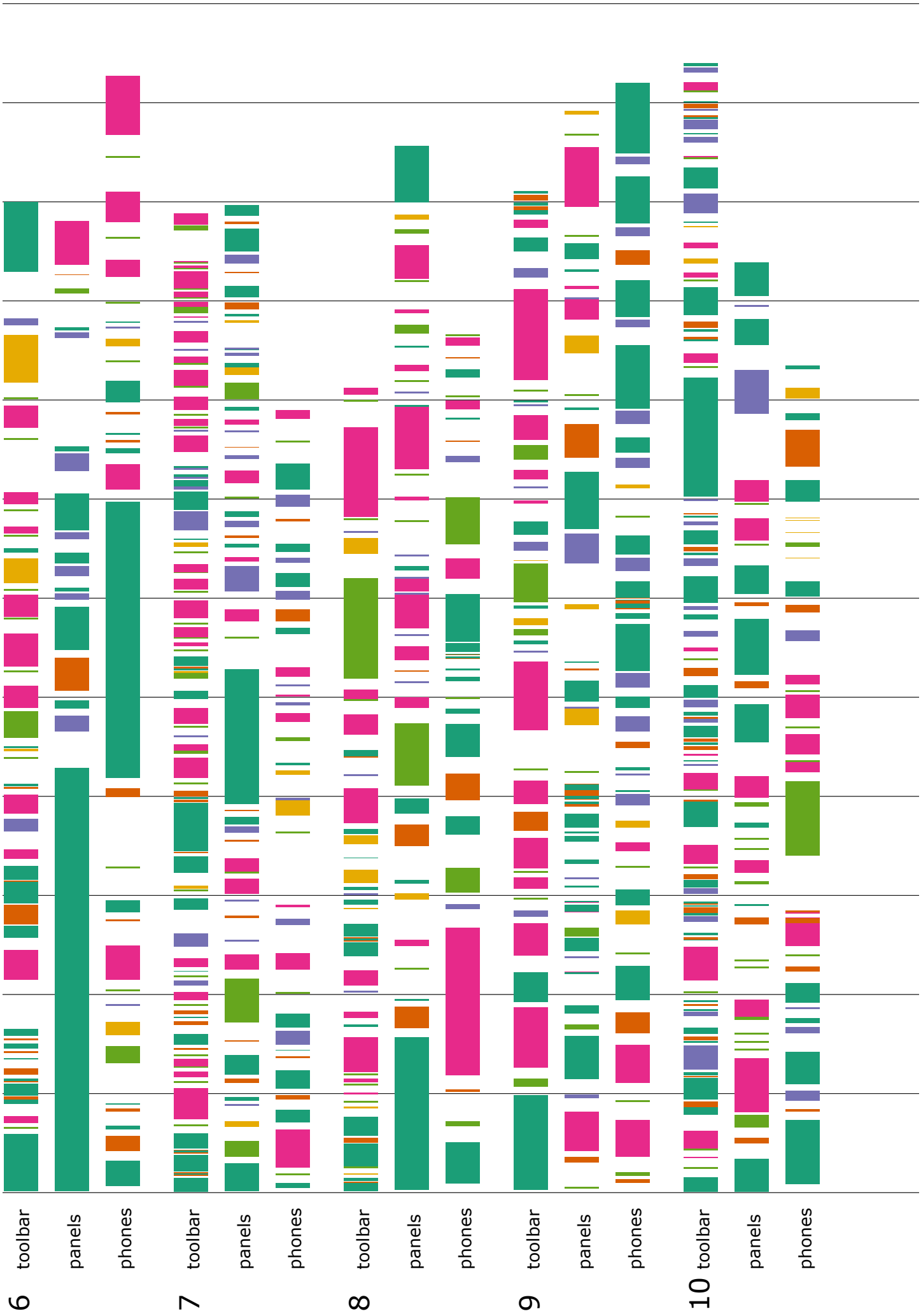


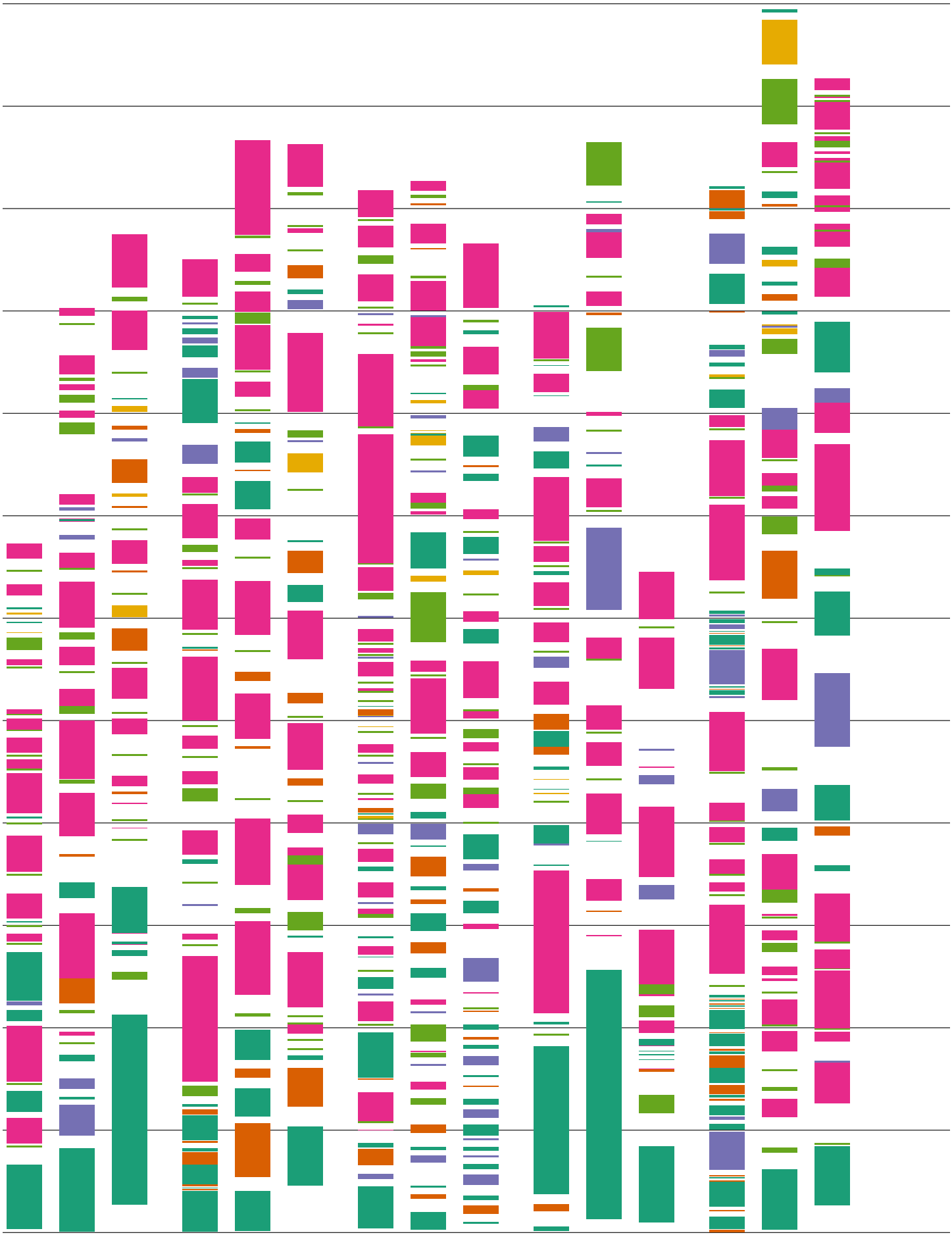
Anmeldungen bitte über studie.interaktiv@gmail.com



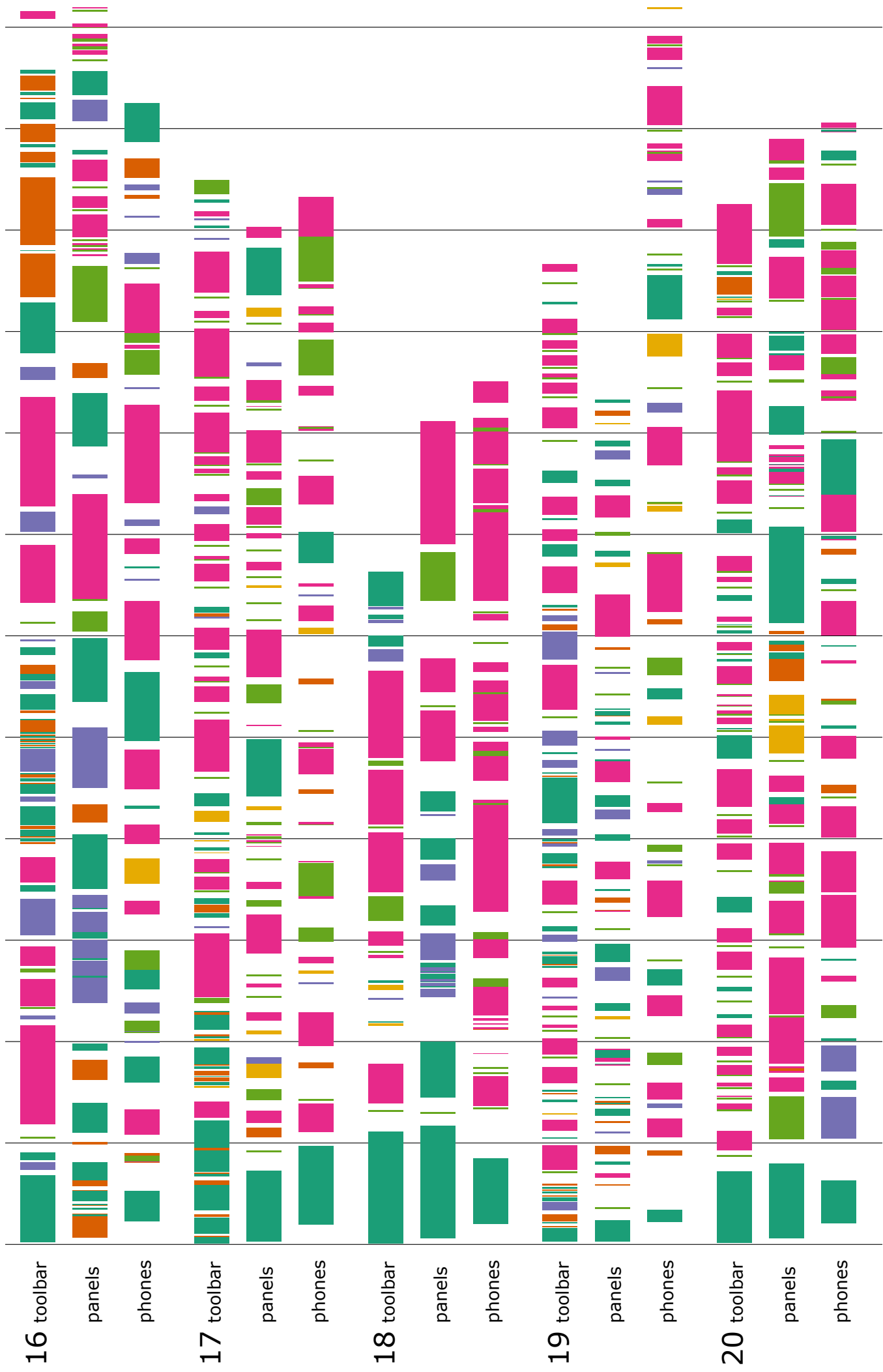
A.7 Scarf Plot of Instrument Usage







11 toolbar panels phones
12 toolbar panels phones
13 toolbar panels phones
14 toolbar panels phones
15 toolbar panels phones



A.8 Attached files

This document is paired up with a USB stick with the following files:

- **Thesis:** A digital version of this document.
- **Video:** shows what the three applications do and the study setting.
- **Distributed Digital Desk:** The system developed to create the necessary applications. A README file explains how to run it.
- **Participant final configurations:** JsonML versions of the final configuration of each participant.
- **Video encoding data:** The resulting data of the video encoding.
- **Log data:** Log data from the tasks participants went through.
- **Questionnaire data:** CSV data of transcribed NASA-TLX and UEQ.
- **Visualization:** HTML version of the scarf plot visualization attached above.
- **Study documents:** Digital versions of all documents used for the study.

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