SimPad – a drawing-based modeling tablet web application to support science education

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Abstract

With the increase of use with tablet computers comes new ways of interaction but also new possibilities for learning. This creates a challenge for designers to create a viable interaction design. In this research, a set of interaction design guidelines and interaction qualities are identified. Specifically when designing natural user interfaces for drawing-based modeling on tablet devices to support learning. The existing tablet computer manufacturer design guidelines are reviewed. Additionally, a web-based tablet prototype designed and developed using an iterative design approach consisting of design and creation coupled with design-based research and interaction design. The prototype is evaluated with eight representative end-users at a middle-school in southern Sweden using a usability evaluation that is recorded with video and analyzed through a significant event analysis. The results show that users enjoy working with the prototype and they think that it can help them in their learning. The results also shows guidelines and affordances for interaction design of interfaces for drawing-based modeling tablet applications. The reasoning behind identifying guidelines and affordances is to provide researchers, designers, and others with the means to minimize problems that may arise in the design of their own drawing-based modeling tools for education.

Keywords
drawing-based modeling, user interfaces, user interaction, interaction design, tablet application interfaces for learning, human-computer interaction
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List of Acronyms

**DBR** Design-Based Research

**DBM** Drawing-Based Modeling

**HCI** Human-Computer Interaction

**ID** Interaction Design

**GUI** Graphical User Interface

**MVC** Model View Controller

**NUI** Natural User Interface

**TEL** Technology-Enhanced Learning

**TELE** Technology-Enhanced Learning Environment
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Chapter 1

Introduction

Drawing, sketching, and scribbling is something we all do from an early age. As early as in primary school and pre-school curricula, we apply drawing as a way of supporting learning [2]. Drawing-based modeling (DBM) is a term that explains the process of how drawings can be used as representations of knowledge and also how learners can utilize this to convey their perception of knowledge [3]. Research shows that use of drawing-based modeling as a key part of science education benefits learning can increase [4]. Representations of knowledge are crucial not only to convey understanding and knowledge, but also in scientific thinking [4]. Part of this research is realized through what researchers have named modeling research and also through the development of PC-based, graphic drawing tablet tools to investigate the place of modeling in science curricula [3,5]. The onset of new mobile technologies such as tablets and especially the prevalence of tablet devices and their ubiquitousness has consequences, among which are technology potential for their use in curricula, and the reduction of the gap between people and their technology [2,5–10]. This gap of this latter consequence refers to the intent of the user and the execution of that intent [11]. By attempting to reduce this gap, one can transcend physical limitations. This can then result in an improved personal experience [11]. A particularly interesting approach for this is Natural User Interfaces (NUIs), where ”natural” refers to the user’s experience of interacting with objects in real-life. These NUIs describe and categorize the interfaces that are attempting to address the aforementioned gap [11].

The research presented in this thesis investigates the design, development and evaluation of a tablet-based prototype with an NUI for DBM in order to identify interaction design guidelines for supporting learning. In particular, the interface design utilizes a combined approach of Interaction design (ID) and Design-based research (DBR). The prototype application uses web technologies to develop multi-
device experience through the design and creation process and is evaluated with usability evaluation.

1.1 Purpose and motivation

The fundamental principle of NUIs is not a menial one: to leverage existing technology by providing novel input actions and affordances (the qualities of an object, or environment, that allows a person or user, to perform a specific action) [12]. However, it also comes with an optimistic promise of enhancing or extending human capability rather than obstructing it. The potential to close the proverbial ”gap” between user intent and execution is a tantalizing prospect, yet it presents some Human-Computer Interaction (HCI) and ID issues. Arguably, NUIs are supporting the development of interfaces where they become less prevalent and the focus is on the experience rather than the interface itself [11, 12]. This development has likely been influenced by the myriad of new input devices that are now at our disposal. Especially prevalent is the tablet device and most prominent is Apple’s tablet device – the iPad, which as of the fourth quarter in 2012 had 43.6% of the market share according to the International Data Corporation (IDC) [13]. In education, these devices become especially interesting, by being what Technology-Enhanced Learning (TEL) refer to as one-to-one devices (one computing device per student) [9]. These devices are promising as they provide the students with a personal computing device, as compared to for example a classroom PC or that of one in a computer lab. Additionally, by owning and utilizing a personal computing device regularly, there could be a change in how students learn [9], in addition to enhancing current ways of learning. One of which is drawing.

Drawing is currently used in several ways in education. In particular, it is used to create representations of knowledge in the form of models that are used for reasoning in the classroom [4]. This is known as modeling and refers to the process of gaining scientific knowledge by modeling phenomena and trying to understand them by reasoning and simulation [3]. The combination of drawing and modeling knowledge results in DBM and provides learners with the means to create drawings, perform tasks, and represent solutions of those tasks through simulation. Previous research projects [3, 5, 14] have the explored potential of a tablet devices in relation to DBM and show promise in terms of learning gains [3]. However, the previous projects have not considered a commonly used tablet device, such as the iPad, nor have they regarded the aspect of interaction design in their interfaces. As such, the potential
benefits with an NUI that can allow the user to perform drawing-based modeling on a tablet device is an open question.

The purpose of the research presented in this thesis is to investigate how DBM simulation tools with NUIs can be developed to potentially support learning. In order to explore this further the research will also include the design and development of a prototype tablet application with an NUI. This interface should allow the user to perform drawing-based modeling in science education. Additionally, the research will investigate and attempt to identify proper guidelines when designing NUIs. This project presents research challenges with the design of an NUI for DBM. Some of these challenges include: how the user should be able to draw, select and manipulate elements with touch, and how the user will assign behaviors to these elements.

1.2 Research aim

The objective of this thesis is the design and development of a web-based tablet application with a NUI. Further, the thesis is also tasked with identifying the affordances of the interface.

1.3 Research questions

The focus of this thesis project is guided by the following main research question:

1. What new interaction design guidelines can be identified for the creation of a natural user interface for drawing-based modeling on tablet devices to support science education?

To deepen the investigation into this question, the following additional questions were formulated:

2. What are the interaction design affordances that come with an NUI for drawing-based modeling?

3. What potential learning benefits can an NUI for drawing-based modeling provide?
1.4 Scope and limitations

This section presents the scope and the limitations of this thesis. The research in this thesis is a collaborative effort between Malmö Högskola and the University of Twente. From the University of Twente comes the main body of research in the area of drawing-based modeling [3,15]. There the potentials with drawing-based modeling (DBM), in relation to education, have been explored through development, testing and evaluation of applications such as GearSketch and SimSketch [2,3,5,14].

The choice of the domain science education is grounded in the thesis supervisors which both have extensive experience in the domain of education. Based on previous research from the University of Twente, astronomy was chosen as this allows for the representation (drawing) of a simple model. In particular the scenario is the solar system and how planets have orbits and other celestial bodies. The choice of this model was based on the earlier research [14] and from recommendation by the external supervisor of this thesis. The choice of scenario is based both on familiarity of the subject matter but also because it is taught to the target demographic of school-children in the ages ranging from 10 to 12 year olds.

However, the research will not include knowledge gain from using the prototype as the focus of the thesis is the NUI for drawing-based modeling as well as the identification of interaction design guidelines for NUI design. The prototype will serve as means to investigate the interaction design challenges.

1.5 Expected results

This thesis will provide interaction design guidelines for NUls in terms of DBM. Moreover, it will also investigate how this can potentially support learning in science education.

In addition to this, the thesis will also create a prototype application with a NUI that will enable the user to perform DBM on a tablet device. This application will enable DBM through freehand drawing of objects and direct manipulation of these objects through touch interaction. Further, the application will be able to assign behaviors to drawn objects which can then be simulated to observe, for example, a learners solution to a task during a class of astronomy and more specifically, about the solar system.
1.6 Thesis overview

The thesis is divided into five chapters. Chapter 2 familiarizes the reader with the subject area and the relevant theory in the domains of HCI and NUI, current ID guidelines from device manufacturers, DBR and ID, technology-enhanced learning (TEL), drawing in education, and DBM. Following this, chapter 3 details the methodological aspects of the research. Chapter 4 explains the prototype architecture and design. Chapter 5 shows the results of the research and chapter 6 discusses the results and details the conclusions on the work, and outlines plans for future work.
Chapter 2

Theoretical background

This chapter presents the relevant background and related work for this research and brings together human-computer interaction and natural user interfaces (HCI and NUIs), current interaction design guidelines from device manufacturers, design-based research (DBR), TEL, drawing and drawing-based modeling (DBM) and also related works in DBM.

The following section explores the area of HCI and NUIs, the evolution of the user interface and how the introduction of new input devices has affected interface development. This section is followed by a review of the current interaction design guidelines from device manufacturers. This section is followed by a history of DBR and its current role in research, as well as the fundamentals for conducting DBR. Since the thesis prototype could support learning in science education, the next section covers TEL, and also important characteristics for TEL devices in educational research. This section is followed by drawing in education accompanied by drawing-based modeling as means to introduce the concepts of drawing and its role in modeling. The existing related research regarding DBM software is then presented in the related works section. The chapter ends with a summary of the gaps that have been identified in the current research and that this thesis is attempting to address.

2.1 Human-computer interaction and natural user interfaces

Since the dawn of interactive computing, there has been a lofty goal of not only making computer technology widely available to the public, but also regarding the computer as an extension of our human capabilities and ultimately as a resource for
what Engelbart called an augmentation of the human intellect [16]. This augmentation is explained by Engelbart as follows: “increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems.” [16]. Engelbart also talks about the co-evolution of tools and practices. This can be crudely simplified as the process of how we throughout history, continuously develop new and radically improved tools, which through use we humans then improve ourselves [16, 17]. To be able to show to the world how this augmentation would look, Engelbart and his colleagues held what is now known as the Mother of all demos (MoAD) in 1968. Here, paraphrasing from author [18], the world was introduced to computing with a mouse. In the crowd that day was Alan Kay, a computer scientist that used influences from Engelbart and his colleagues’ demo to synthesize what has become known as the Graphical User Interface (GUI). The GUI was something completely new in interactive computing and allowed computers to be operated by everyone rather than only scientists [18]. Something Kay realized early on was how designing intuitive interfaces necessitated the understanding of human perception [18]. In order to build upon this Kay came to an understanding of how to represent things in this GUI, which also became its basic premise. This representation Kay called “doing with images makes symbols”. In essence this meant that users of the computer could perform different tasks on the computer by the manipulation of icons on the computer screen in real-time [18]. This later came to be known as WIMP-interfaces (Windows, Icons, Menus and Pointer). But what Engelbart and Kay in essence saw, was the potential of the technology and the possibilities that came with it. Yet despite the advances in the current technology with new ubiquitous devices and possibilities for multi-touch-based interaction and how adept we humans have become at using them, the interfaces for them have not shown a similar development pattern [12]. However, there are some that claim that by creating different types of interfaces we can collectively level out these different development patterns and perhaps change, fundamentally, how we interact with technology [11, 12]. This development of both technology and human, ties directly back into Engelbarts vision of co-evolution between humans and their tools [17]. These ”new” types of interfaces have been collected under the term Natural User Interfaces (NUIs). The term seems to have several definitions in literature. It is used to describe what human-computer interaction (HCI) researchers refer to as post-WIMP interfaces [11]. The post-WIMP interfaces also refers to the development of interfaces which is regarded as having passed through these different phases as seen in Table 2.1 (adopted from [12, 19]).
It should be noted that although NUIs are usually associated with multi-touch based interfaces, and therefore devices that have multi-touch technologies, the technology behind touch screens has been researched for several decades. Buxton states that the first true multi-touch system that was designed for human input into a system was developed in the 1980s [20].

The term NUI is also used to encompass different types of devices that all have different ways for the user to interact with them. To mention a few devices that are commonly categorized as having an NUI, there are: multi-touch tables a.k.a. table-top tablets, multi-touch mobile devices (such as smartphones, iPads or Google’s Nexus tablets), and arm-gesture controlled gaming console peripherals like Microsoft’s Kinect for their gaming console Xbox [21]. The argument for naming these types of interfaces is due to how we as humans interact with them. An example of a simple NUI could be the way you can sort pictures on your Apple iPad. The interface is intuitive enough that the user can, without almost any guidance, figure out how to use it. The reason why this is intuitive is because it closely resembles how we would sort physical copies of photographs in reality; by taking the photographs and sorting them into piles and then albums. Such an interface, which mimics reality, is likely going to be intuitive [21]. With these new input devices they: “could be enablers for the creation of a UI that is more natural to use, and could fundamentally change the way we interact with technology” [12].

However, an NUI is not only concerned with being intuitive. In fact an NUI is an interface that also allows the user to interact with it in a natural manner that is, the “natural” in NUI refers to the user’s behaviors and feelings during the experience of using the interface [12].
2.2 Current interaction design guidelines from device manufacturers and device ergonomics

As the devices that will run the prototype utilizes touchscreens the guidelines that this research aims to identify need to consider the possibilities, and limitations of this technology. Each major tablet device manufacturer (Apple, Google and Microsoft) has their own guidelines and patterns for interaction design [22–24] for their respective devices. Additionally, ergonomics for the device are also of importance, as not considering how humans actually uses the device when creating an interaction design, can cause physical stress [25].

In Microsoft’s Windows 8 Touch Guidance document [24] the aspect of how users actually uses (grips) a tablet device in what they call ”Touch Posture”. There it is illustrated how this affects the user interaction with the device as seen in Figure 2.1 (taken from [24]).

![Figure 2.1: The four most common ways to hold a tablet](image)

On his website article [26] Wroblewski illustrates further ways that users use a tablet device as seen in Figure 2.2 (taken from [26]).

These grips also affect the different interaction areas on the tablet screen. Depending on the way the user grips the screen the difficulty of interacting with objects
on specific areas on the screen varies as illustrated, also by Wroblewski [26] in Figure 2.3 (taken from [26]).

As for the individual device manufacturers guidelines there are some similarities and most of them, put emphasis on native applications rather than web-based applications. To illustrate the differences and similarities between them see Table 2.2.

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Apple</th>
<th>Google</th>
<th>Microsoft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design for direct manipulation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Utilize gestures</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Provide meaningful feedback to the user</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Be consistent in the UI</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 2.2: Interaction design guideline comparison

With the current guidelines considered, the way the research in this thesis will approach design is addressed in the following section.
2.3 Design-based research

A question that researchers such as Simon [27], have been arguing for, is the role of design in research and therefore also a science of design. There’s research suggesting that the distinction in definition between design and research should not be made so easily [28]. If one considers the process of research and the outcomes of that, i.e. research papers, tools, techniques, methods and so on, one could state that those artifacts are products and have been designed, to some extent, by the researcher.

However, the concept of design in research is not a novel one. The history of design and its relation to science and research goes back in history, more specifically to the 1920s and the Bauhaus, where the designers were looking to design and create products in a scientific manner [29]. This approach to design was then spread across different corners of the world with the closing of Bauhaus.

Later in the 1960s, the attempt was made to make existing design methods more scientific or rather come up with a scientific design process [29, 30]. It was also around this time that the The Conference on Design Methods [31], which launched an interest in design methodology as a field to explore, was held. This later made way for different initiatives to start more research in the field. In particular, Simon [27], raised the important issue of making design theory precise and explicit and especially to be able to incorporate computers in the process.

For the last couple of decades DBR has seen an uptake in educational-related research projects [32,33]. DBR, a methodology for the study of function, also known as design research or design experiments, is primarily concerned with generating domain-specific theories as means to interpreting learning practices [32]. DBR also states that the use of design in the learning context is to bridge the gap between theory and practice [32]. Today DBR is used in a variety of other domains in order to solve complex problems or provide novel ways of discussing issues in that domain. However, the fundamentals of design research stay the same. The fundamentals are as shown in Table 2.3 (taken from [32]).

2.3.1 Intervention creation in DBR

Another important aspect of DBR is that of intervention creation. Brown [34], who is one of the researchers who helped develop DBR for education, emphasizes the importance of intervention creation in design experiments. Brown states that intervention creation, or “theory of learning”, should be used to inform practice in classrooms and should be supported by both personal and realistic technical support [34]. Shattuck and Anderson [35] build upon Browns’ emphasis and state
Table 2.3: Design research fundamentals

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design research is concerned with the physical embodiment of man-made things, how these things perform their jobs, and how they work.</td>
</tr>
<tr>
<td>2</td>
<td>Design research is concerned with construction as a human activity, how designers work, how they think, and how they carry out design activity.</td>
</tr>
<tr>
<td>3</td>
<td>Design research is concerned with what is achieved at the end of a purposeful design activity, how an artificial thing appears, and what it means.</td>
</tr>
<tr>
<td>4</td>
<td>Design research is concerned with the embodiment of configurations</td>
</tr>
<tr>
<td>5</td>
<td>Design research is a systematic search and acquisition of knowledge related to design and design activity</td>
</tr>
</tbody>
</table>

that the intervention creation is a collaborative undertaking between the researcher and the practitioners. Additionally, they state that such an intervention can be: “a learning activity, a type of assessment, the introduction of an administrative activity (such as a change in holidays), or a technological intervention...” [35]. The technological interventions are, according to Shattuck and Anderson’s research, most prevalent in DBR-related studies, and they are mostly concerned with the use of online and mobile technologies [35]. DBR studies are interventionist as the actual design experiment typically involves testing some technological innovation [33]. The creation these technological interventions relates directly with the area of TEL, which is also concerned with supporting and improving learning through the use of digital technologies [10].

2.4 The importance of technology-enhanced learning

Technology is a an increasingly larger part of our lives. With new devices, faster and more widespread internet connections coupled with more ubiquitous experiences the possibilities seem endless. The use of technology in a classroom is, like design in research, also not a new concept. Since the early years of computing researchers and learners have seen the potentials of utilizing the power of a computer in an educational setting creating what research calls Technology Enhanced Learning Environments (TELEs) [36]. Currently in Europe, most schools have computer rooms or in some countries like in Sweden some schools have even gone as far as promising
every student their own PC, an ongoing initiative named "one-to-one" [37]. This is a core part of TEL, also known by names such as "computer-assisted learning," "e-learning," and "m-learning". As Chan et al. [9] state, TEL can be further explained as how one utilizes socio-technological innovations to enhance or assist in human learning - specifically with digital technology.

However, with this rapid development of technology comes an increase in complexity. Additionally, the size of it has decreased and the availability and affordability to the public has increased substantially. This has resulted in a myriad of different devices that are at our disposal today. Considering tablet devices as an example, according to the IDC, an estimated that 172.4 million tablet devices will be sold during the year 2013 [38]. With this large amount of devices available and their continued rate of improvements, educational researchers have become interested in how these devices are utilized in a learning environment [9]. Further, these researchers are also interested in the actual learning gains that could be affected with their use.

### 2.5 Drawing in education

To explain why drawing should be considered as a key part of learning in science education researchers have identified five different ways one uses drawing in science education [4]. One should note that drawing is not only used to illustrate ideas but also in other ways as shown in Table 2.4 (adopted from [4]).

<table>
<thead>
<tr>
<th>Application of drawing</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing to enhance engagement</td>
<td>When drawing students become more motivated.</td>
</tr>
<tr>
<td>Drawing to learn to represent in science</td>
<td>When drawing students deepen their understanding of specific representations</td>
</tr>
<tr>
<td>Drawing to reason in science</td>
<td>When drawing students reasoning improves through refinement of modeling</td>
</tr>
<tr>
<td>Drawing as a learning strategy</td>
<td>When drawing students has to make explicit understandings of knowledge</td>
</tr>
<tr>
<td>Drawing to communicate</td>
<td>When drawing students can explain their line of thought to peers and teachers</td>
</tr>
</tbody>
</table>

Table 2.4: Applications of drawing in science education.

By using drawing, students make their thinking more explicit and specific [4]. It would also seem that there is a correlation between the engagement in students and creating representations of knowledge through drawing [4]. Further, using drawing
activity to comprehend scientific texts has been shown to benefit learning more as opposed to conventional text-focused instructions [39].

2.6 From modeling to drawing-based modeling

The creation, modification and evaluation of models in science is fundamental to gain understanding of phenomena [3]. The process of modeling can be explained as the process of construction, execution, and evaluation of external representations of systems [40]. By constructing an external model the model becomes freely available to the world and also offers it up for scrutiny. Putting this into the context of education, as the previous section details about drawing, an external model can also help explain a student's ideas and thoughts to fellow students, teachers also to themselves [40].

However, creating these models, especially on computers, is challenging because of the interrelations between the model elements, their respective behaviors, and the evaluation of those behaviors. During the creation of models learners seem to not always apply previous knowledge and have a hard time translating knowledge when creating a computer model, and rather focus on the model as an artefact that is supposed to just function [40]. To create effective representations for modeling the properties of a phenomena, and the relations between them, should be made explicit and visible for the learner [3]. One suggested way to support the activity of modeling is that of drawing. As the previous section explains, drawing is already used in science education by students to discuss, convey, and more explicitly explain one’s thinking process. As an example, often when tackled with a problem, sketches are created to explain the issue with someone else but also to get an overview. Similarly, these sketches or drawings could be used to create an informal model, since such a model does not need to function. In fact, novel modelers can more easily focus on expressing more of their knowledge through drawing rather than in a formal model [40]. By drawing the model firsthand the drawing could act as a foundation for the computer to generate a formal model. Depending on the sophistication of the software the drawing model could then become the model. As an example consider a simplified model of the solar system: plants revolve around their axis and planets all orbit the sun. A child could draw this as an informal model and then have the software interpret the drawing. Upon doing this the drawing-based model could then be simulated. This is in essence what drawing-based modeling is trying to achieve and the related works in this area is explained in the next section.
2.7 Related work

At the University of Twente there have been several developments in the area of drawing-based modeling [2, 3, 5]. In some of these projects, drawing-based and simulation-based software has been developed and tested. These research efforts and their respective software applications are described in the following sub-sections which is followed by a short explanation of how the prototype for this thesis will differ from the previous research.

2.7.1 SimQuest

*SimQuest* is an authoring system for generating computer simulations that are embedded in an instructional environment. It was created to support both teachers and learners that are involved in discovery learning [41].

SimQuest is an object-oriented system that holds many predefined objects. These objects are used to create a learning environment. Example of these objects are: simulation models, interface elements, instructional measures, and test elements. Because SimQuest is object-oriented, each element that it holds in its library behaves according to a specific interface protocol. These protocols gives SimQuest the ability to edit, copy, and link elements.

The goal of discovery-learning environments is to construct knowledge from the investigated knowledge domain [41]. In SimQuest this is done through a process of orientation, hypothesis formation, experiment design, prediction, and data analysis, as well as planning and monitoring [41].

SimQuest is also divided into two entities: a learner view (see Figure 2.4, taken from [42]) and an authoring environment (see Figure 2.5, taken from [42]). In the learner view the user can manipulate input parameters and view the responses of those manipulations through the simulation response. A simulation could be showing a car that is driving along a road. The corresponding input parameters could then be the initial position of the car, initial velocity, and acceleration. By manipulating these inputs the user can view the effects on the simulation.
Figure 2.4: An example of a SimQuest application. This is Motion which is about acceleration, velocity and acceleration.

In the authoring environment the user can create their own SimQuest-based multimedia learning environment. This is done by selecting elements from the SimQuest library (left in Figure see Figure 2.5) and dragging them into an application (right in Figure 2.5).

Figure 2.5: Showing how to create SimQuest applications in the authoring environment by dragging and dropping.
2.7.2 GearSketch

GearSketch is a desktop drawing-based simulation environment targeting the domain of how gears work. [5]. With this application learners draw gears and chains and also create simulations based on this. The learner is assisted in creating these simulations by GearSketch. Drawn circles are turned into gears and paths created around gears turn into chains.

![GearSketch example](image)

Figure 2.6: Showing an example gear and chain setup in GearSketch.

GearSketch also provides the learner with instructions, questions and also puzzles that they can solve in the gear domain. With GearSketch a study was performed that showed promise for simulation-based support in a digital drawing environment and that this can lead to higher learning gains [3].

2.7.3 SimSketch

The continuation of GearSketch is SimSketch. This software bridges the gap between the informal drawing-based representations and formal executable models. This application can be used to draw models as well as assign the objects that are drawn with specific properties and relation which then animates the drawing. This is done through the learner drawing strokes which represents the learner’s informal drawing-based representation [3]. Upon finishing this, the learner can assign “stickers” to the drawing that each represent a behavioral primitive, such as move, reproduce, avoid etc [3]. After having assigned the behaviors the model can then be executed and simulated [3]. SimSketch is targeted toward learners in primary and secondary education in several domains because the behavioral primitives are highly generic and can be used to describe phenomena in other educational domains such as the
movement of celestial bodies in the solar system, predator and prey systems and even bacteria (see Figure 2.7) [3].

![Figure 2.7: Showing an example bacteria model and simulation in SimSketch.](image)

These research projects are all at some level concerned with either drawing-based modeling or modeling and simulation, or a combination of them. What will set this thesis prototype, named SimPad, apart from these previous works is that it will attempt to bring the drawing-based modeling and simulation aspect to a tablet device with a multi-touch. Further, this prototype should feature a user interface and interaction design that is adapted for finger-based touch (i.e. multi-touch), meaning tablets devices such as Apple’s iPad or Google’s Nexus tablets.

2.8 Theoretical reflections

In the previous sections of this chapter, we reviewed related and relevant literature and identified key factors in NUI design, DBR, TEL and drawing as well as drawing-based modeling.

With the multitude of multi-touch devices and the growing tablet market [38] the concept of Bring Your Own Device (BYOD) has become an interesting prospect for educational practitioners as well as researchers. The use of these devices in a classroom environment has also spawned a research field of its own with TEL. Other educational researchers have also utilized this technology and combined it with drawing, modeling and simulation to create novel educational software for students to go about creating and understanding representations of knowledge. Although
there has been previous research projects looking into how to create applications for a tablet device with multi-touch capabilities to support or enhance learning [2,5,6] some gaps still exist.

The findings regarding related works and the areas: natural user interfaces, interaction design, design-based research, technology-enhanced learning and drawing-based modeling, provides initial insight into the problem area. By looking at the current existing interaction design guidelines from devices manufacturers gave more insight into the challenge of how to design an natural user interface that allows for drawing-based modeling. Arguably, the affordances of the interface are of importance and drawing-based modeling ostensibly imposes additional constraints on the interface.

The following chapters will present the research methodology that was utilized in order to investigate the aforementioned challenges and the development method that was used to develop the prototype. Additionally, the empirical findings of testing and evaluating the NUI will be presented and discussed in relation to drawing-based modeling and the potential learning benefits of using an NUI for education.
Chapter 3

Research methods

The design, development and implementation of a learning tool with an NUI interface on a tablet device to support learning presents design challenges that span the domains of human-computer interaction, interaction design, and TEL. In order to address these design challenges the methodological approach of this thesis utilizes the design and creation approach from the standpoint of DBR. As design and creation has an emphasis on the development of an IT artefact, and because the resulting artefact is to be considered in an educational context, the design and creation approach is not sufficient to address the design challenges. Therefore DBR, primarily through the lens of ID, is applied to address the context of learning as well as to lessen design challenges. The chapter starts with explaining how design and creation was applied and is followed by DBR and ID, which presents how the different quality aspects for DBR was addressed and also how the ID process is applied. The next section shows the prototype development process which explains the process of development as well as the architectural choices.

3.1 Design and creation

Design and creation, also known as the design science approach, is utilized in research where the objective is to develop new IT artefacts [43]. This type of research contributes to knowledge through what design and creation calls constructs, models, methods, and instantiations – which can be fully implemented systems or prototypes [43,44].

The process of performing design science is based on a ruleset for performing the research and can be represented by a mental model (see appendix A).

Although the model is presented in a nominal sequential order the researcher is not always expected to go through it in a sequential order [1]. The model also
presents different entry points for research. In the case of this thesis, the entry point is design- and development-centered initiation. According to the model this means that the approach is initiated with the activity of design & development. The design & development activity is based on the existence of an artefact that has not been fully realized as a solution in the problem domain that it will be used in [1].

As means to realize the artefact, in the form of a prototype, this thesis will follow the iterative process of the design and creation strategy. This process consists of five different steps: awareness, suggestion, development, and evaluation and conclusion [43]. The following sections will explain each step in the design and creation strategy and how it was applied.

3.1.1 Awareness

In this thesis the awareness step, which should articulate or recognize a problem [43], is defined through the gap in the current research. The gap refers to the design of a NUI. Further, it also refers to how this NUI should enable drawing-based modeling. Additionally, the affordances of the interface are of importance, and with the domain of education comes the challenge of cognitive load during use. Additionally, due to the fact that a multi-touch tablet device by design is more ubiquitous than a PC, and because it holds different modes of interaction, there is an added complexity to the interaction design.

3.1.2 Suggestion

The suggestion step should consist of a creative or tentative idea of how to solve the awareness of the problem [43]. Therefore, with the definition of the problems from the previous section in mind, the suggestion step for this research lies in the design of the NUI as well as the identification of the interaction affordances for the interface as well as identifying guidelines for NUI design for multi-touch tablet devices that will support drawing-based modeling.

3.1.3 Development

In the development step the suggestion is implemented. How the implementation is done is dependent on the type of artefact that is going to be developed. In the case of this research, the artefact is represented by the prototype. The actual development method of the application will be done through prototyping. The prototyping will
be done using the throw-away prototyping approach [45], meaning the prototype that is developed will not, nor should, be used as a finalized product but merely act as means to explore the problem area with the end-user. This is chosen due to the fact that the requirements nor the technical feasibility is clear from the outset of the research process. Through iterative prototyping, and evaluation, the requirements are captured and refined.

3.1.4 Evaluation

In design and creation the evaluation step is used to examine the developed artefact and seeks to assess how it lives up to, or deviates from, the expectations [43]. In this research, the evaluation step consisted of usability testing in order to validate the prototype [46]. This method, and its application in the research, are explained further on in section 3.4.

3.1.5 Conclusion

The final step of the design and creation process is the conclusion step. Here the achieved and unexpected outcomes of the project are detailed alongside the knowledge gained [43]. The unexpected outcomes can also be used as a basis to detail further research.

3.2 Design-based research and interaction design

The choice of DBR from that of other research approaches lies with the introduction of the education domain. This could be attested to the fact that in recent developments DBR has become a popular methodology in educational science [32]. It is also partly due to the fact that the prototype could potentially be used to measure knowledge gain in continued research efforts. What most DBR studies also show, over quantitative studies, is that instead of generating measurable data to determine what is viable, it provides a description of the context, design process, implementation, development and what design principles emerged [35]. Additionally, since the work of this thesis will go through iterations, during and after this thesis project, DBR can be applied since it utilizes cycles of research [10].

There are several defining aspects to a quality DBR study. The defining aspects are explained in Table 3.1 (adopted from [35]).

In this thesis the aspects (1) and (2) are achieved through the design and testing of a prototype tablet web-application in a educational context. As for (3) the use
<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Situated in a real education context.</td>
</tr>
<tr>
<td>2</td>
<td>With a focus on the design and testing of a significant intervention.</td>
</tr>
<tr>
<td>3</td>
<td>Use of mixed methods.</td>
</tr>
<tr>
<td>4</td>
<td>Involves multiple iterations.</td>
</tr>
<tr>
<td>5</td>
<td>Collaboration between practitioners and researchers.</td>
</tr>
<tr>
<td>6</td>
<td>Evolves design principles.</td>
</tr>
</tbody>
</table>

Table 3.1: Quality aspects of a DBR study.

Of mixed methods DBR is agnostic in choice of methodologies [35]. It is left to the researcher to apply the appropriate methods as they see fit. As a result, and also because of (4) and (5) the methodology of this thesis consists of a combined approach of interaction design and DBR. The blend of DBR and interaction design is something other research has attempted as well [10]. The motivation for combining these is not only because the two compliment each other, but also because they can diminish the design challenges [10]. This combination between DBR and interaction design can be seen as an attempt to evolve existing design principles (6).

### 3.2.1 Interaction design life-cycle

For this research the interaction design lifecycle see Figure 3.1 (taken from [46]) serves as the basis for generating initial requirements, designing and developing the prototype. Additionally, since the lifecycle model is iterative it also adapts well to the iterative nature of DBR. DBR can then act as the balance between theory and the generation of an artefact [47].

The initial requirements are generated by looking at the previous drawing-based modeling applications SimSketch and GearSketch. This was done together with the external supervisor for the thesis during the initial phases of this research project. During this session the supervisors, which can both be considered experts in their respective fields, provided insights from their own research. Collectively, a fictive scenario and persona was formulated. This was then used to identify the constraints and the situation in which the prototype would be utilized in, much like the initial stages of the goal directed design process, which include generating what Cooper [48] refers to as persona of use for the product or object that is being designed and then formulating fictive "everyday” scenarios for that persona. By doing this, the specific requirements that was needed for the persona to accomplish their tasks in the scenario can be identified more easily.
3.3 Prototype development method

The development method for the prototype followed an *incremental model*. The main principle behind the incremental model, as opposed to the conventional waterfall model, is that the end product is delivered in small chunks that contain new functionality or features [45]. These chunks are called increments. In order to have this operational the first increment of the prototype needs to have an overall software structure (also known as a *kernel*) in place before the next increment is started.

This incremental model is then applied to the prototyping process which then becomes evolutionary prototyping, which is more commonly known as *iterative development* [45]. This model works in much the same way as the incremental model, but also incorporates feedback. That feedback is then used to adjust the requirements which can then lead to changes in the prototype.

3.4 Evaluation

In order to investigate the utility as well as if the prototype achieved the requirements that are defined in chapter 4, the prototype is evaluated using formative usability evaluation. The process of the evaluation in this research consists of the prototype evaluation (Section 3.4.1), which is done through a form of usability evaluation. Further, as the usability evaluation is recorded, a video analysis is performed (Section 3.4.2). Lastly, as a way to gather domain knowledge from and the motivation of the participants of the usability evaluation, two types of questionnaires were utilized (Section 3.4.3).
3.4.1 Prototype evaluation

Evaluation of user interfaces can be performed in four different ways: By utilizing a specific analysis technique one can formally evaluate the interface. It can also be done automatically by using a piece of software that automizes the process. It can be done empirically with experiments that incorporates test users, and heuristically by looking at the interface providing comments and judgements based on one’s opinion [49]. Andrews expands on this by classifying the evaluation methods into categories depending on their function [50]:

- **Exploratory**: Provides evidence for how an interface is used and for what it is used for.
- **Predictive**: Produces estimates on user performance based of an interface design.
- **Formative**: Provides feedback on the design, usually in the form of a list of design problems and/or possible solutions.
- **Summative**: Provides an overall assessment of one or several interfaces, usually in form of numerical data and then statistically analyzed.

The evaluation that was performed for the prototype was formative. This was due to this particular research not being concerned with the discounting of a hypothesis but rather to identify ID affordances, as well as investigate the prototype’s potential benefits to learning in science education. Additionally, since the prototype was only concerned with being tested in a specific domain the formative methodology is fitting since the prototype does not need to expose its entire functionality but only that which is needed to complete the specific test objective [51]. As the method will be formative the objective is to examine the effectiveness of a preliminary design concept [51]. Thereby, the following questions were also investigated during the testing:

- How easily and successfully do users get started with modeling knowledge?
- What steps does the user perform to create a knowledge model?
- How well does the application support the steps and goals of the user? That is, how closely does the organization and flow of the application match the users expectations?
- What common obstacles does the user encounter on the way to completing the simulation of a knowledge model?

- What questions does the user ask as they work through their modeling?

- How do users feel about how long it takes them to complete a knowledge model, both in the perceived amount of time and the number of steps?

The following section will explain the usability evaluation method and how it was applied to evaluate the prototype and how it addresses the aforementioned questions.

**Usability evaluation**

The process of usability evaluation, also known as usability testing, is concerned with observing representative end-users of an artifact and simultaneously observe them while they perform realistic tasks [51]. Usability evaluation is commonly used when designing user interfaces because it provides the researcher or designer, with the means to test an artefact as to ensure that it actually performs as expected and meets usability criteria [52]. The purpose behind doing usability evaluation varies depending on context. In academia, it is employed as a tool to validate unprecedented design ideas and systems. This is usually done by illustrating how human performance or work practice is improved through a comparison of the novel design idea and other existing ones [52].

Regardless of the context, there are generally two approaches to performing usability evaluation: *formal* and *informal*. The difference between the two approaches lies in the basic methodology that usability evaluation is derived from, namely classic *experimental methodology* [51]. The formal approach is concerned with the generation, testing and refuting hypothesis about the evaluation artefact [51]. Additionally, the sample size in the formal approach is significantly larger than that of the informal as it is concerned with generating statistically significant data between control groups [51].

In the research presented the informal approach is used to perform usability evaluation and uses a within-subjects design. Each participant will conduct a major task process that contains three sub-tasks. The major task consists of participants attempting to draw several objects, group these objects, assign them multiple behaviors and then simulate the created model. The subtasks are as follows:

- All participants will use the SimPad application to create a model representation of the solar system.
• The participants will use freehand drawing to create elements.
• The participants will manipulate the drawn elements.
• The participants will group drawn elements.
• The participants will assign behaviors to the elements.
• The participants will save their progress, reload the application and continue working.
• The participants will try and use the other tools in the application to:
  – Use different colors
  – Clear the canvas
  – Redo and undo drawn paths
  – Remove drawn object

Each participant performed all tasks using SimPad. An estimated 15 minutes was devoted for each participant. Before each user started their session the testing coordinator explained the session to the participant and he or she was asked to fill out a pre-test questionnaire (see Appendix E). The questionnaire is used to ascertain the participants current knowledge of the solar-system. After completing the pre-test questionnaire the participant conducted the tasks and were asked to think aloud. Upon completion of the tasks the participants were asked to fill out a post-test questionnaire with the same questions as the pre-test. In addition to this, the participants also filled out an additional questionnaire on how they felt about working with SimPad and the tasks. The participants could answer on a 4-choice Likert scale from "totally disagree" to "fully agree" (see Appendix E).

The participants for the usability evaluation consisted of 8 middle schoolers from a middle school in Sweden. The usability evaluation was recorded using a mobile field testing kit that consisted of a Sony HD handy-cam, a GoPro Hero HD 2 camera, a 2nd generation iPad (WiFi only), another 2nd generation iPad (3G+WiFi), an iPad mini, and a MacBook Pro (late 2011). The MacBook used an application called Reflector to allow recording of the iPad screen.

In order to address the additional questions that were stated earlier in this chapter, the participants will be encouraged to "think out loud" while performing testing tasks. Whereby the recorded material can be analyzed to provide potential answers to the questions. The chosen analysis method for the video analysis is based on what Ash calls Flow Chart and Significant Events [53]. This methodology is further explained in the following section.
3.4.2 Video analysis method

Despite being a powerful tool for collecting data, video recording also faces researchers with problems. Through her research, Ash [53] proposes a multi-leveled methodology of video analysis in science sense-making. The first level, being holistic, Ash calls the Flow Chart, which is used to provide an overflow of a session [53]. Level two is called, Significant Event (SE), which looks at one part or segment, of the Flow Chart and analyzes it in more detail [53]. In the second level the focus is on dialogue, content and the tools that are used to make sense of the science involved [53]. The last level, Dialogic Analysis, focuses on a more detailed analysis of the SEs.

In the research presented in this thesis the two first levels were deemed most fitting as the prototype evaluation is more concerned with the utility rather than the learning outcomes of performing the tasks within DBM. The evaluation session was charted based on the task the participants were performing at a specific point in time. The specific tasks then represented the SEs in this analysis and were looked at in more detail as to see how the participants reason on their modeling of the knowledge domain.

3.4.3 Questionnaire design

Domain knowledge. In order to test the participants knowledge of the domain, they were asked to fill out two questionnaires. One pre-test and another post-test. The questionnaires were identical and held seven multiple-choice questions about the solar system (see Appendix E). The design of this questionnaire was supplied by the external supervisor and is based of previous work by researchers Vosniadou and Brewer [54], that have comprised a list of misconceptions children have about the solar system. Some of the misconceptions that children have are as follows: the earth is the center of our solar system, the clouds cover up the sun during nighttime, and the sun is a planet, rather than a star [54,55].

Participant motivation. This questionnaire consisted of twelve items (see Appendix E) and was used to ask participants about their perceived competence and whether or not they found the task they were asked to perform interesting and valuable. The questions were measured using a Likert Scale consisting of four equal interval scales. The reason for choosing a four point scale lies in the social desirability bias which comes from the participants desire to please the researcher. Garland [56] states that by omitting the neutral mid-point in a Likert scale, the bias can be minimized.
Chapter 4

Prototype

The availability, affordability, and the possibilities that come with multi-touch devices make them interesting from a TEL perspective. Creating meaningful applications for these devices to support learning faces designers with HCI as well as ID challenges. As a way to address this, the research presented in this thesis develops a prototype in order to identify ID affordances as well as to identify ID guidelines. Specifically, in the domain of DBM and with an NUI.

As the prototype was developed using an iterative development approach, coupled with the end-user device being a tablet, imposes some architectural constraints on the prototype system. First, since the prototype is to function on several different tablet devices the need for a common development platform is apparent. Therefore, creating the prototype as a web-based software application is fitting, as this allows the same code-base to be run on across several different tablet operating systems. Additionally, as the process of drawing and simulation is a complex task, there is a need for frameworks to be able to execute the basic operations needed to perform drawing, modeling, and subsequently simulation. Furthermore, the frameworks also provide a needed structural basis for the prototype development and can prospectively accommodate additional iterations of development. This chapter will describe the prototype architecture and briefly explain the use of the different JavaScript frameworks that the prototype utilizes, as well as the design of the prototype.

4.1 Prototype application architecture

In the words of Osamani: “The goal of all architecture is to build something well; in our case, to craft code that is enduring and delights both ourselves and the developers who will maintain our code long after we are gone.” [57]. In the same vein the architecture of SimPad should be designed with the ease of expandability in mind
but also as to organize the codebase. A common way in most existing JavaScript frameworks is to follow what is known as the Model-View-Controller (MVC) architectural design pattern which was originally created by Trygve Reenskaug when he was working on the programming language Smalltalk-80 but popularized by the "Gang of Four" in their book on design patterns [58]. MVC separates the concerns in an application into the following entities:

- Models - holds domain-specific knowledge and the data of the application. A model can notify other entities when changes to it occurs, also referred to as the application object [57,58].

- Views - hold screen representation of the application object [58]. It constitutes the User-Interface (UI) of the application [57]. It can observe models but does not directly communicate with them [57].

- Controllers – handles the way the UI should react to inputs from the user. [58]

However, as Osamani points out, not all MVC-based JavaScript frameworks follow this explicit pattern. Some frameworks deviate from this and fuses the role of the controller into the view [57]. These types of frameworks are referred to as MV*, since the application is likely to have models and views, but a separate controller might not be present [57].

For the prototype in this thesis, the main architectural JavaScript framework that was used was Backbone.js. Backbone.js is a MV* type framework \(^1\) that is used to decouple concerns and separate logic in applications. The choice of this as the framework to use was based on the breadth of the documentation available but also the available support for third-party plugins.

Because Backbone.js does not specifically tell developers that use it how to organize their code, developers can then use another JavaScript library called Require.js. Require.js is an Asynchronous Module Definition (AMD) script loader and is used to load the developers’ JavaScript-files asynchronously, manage dependencies, but also to allow the developer to organize their JavaScript into separate modules where each file represents one module. Require.js is also commonly used for optimization (concatenation, minification) of code in a JavaScript application as to increase performance. The choice of Require.js is based on two main aspects: the first being that of dependency management, and secondly that of optimization of the codebase through concatenation and minification.

\(^1\)For a more detailed and in-depth look on Backbone.js see the open-source book by Addy Osamani available here: http://addyosmani.github.io/backbone-fundamentals
As the prototype also needs to incorporate drawing and simulating several libraries for supporting this was considered. For drawing, the chosen library were *Fabric.js*. Fabric.js is a JavaScript canvas library that provides the application with the ability to manipulate the canvas element, which is part of the HTML5 specification. The canvas element allows for dynamic graphics drawing via rendering of 2D shapes and bitmap images. Fabric.js provides numerous features but the ones that made it especially fitting for this thesis prototype is the support for touch events, creating subclassing on elements on the canvas, and serializing the canvas to JavaScript Object Notation (JSON), and also built-in animation capabilities. These features allowed for the basic capabilities that the prototype needed in order to have a DBM experience.

To run the application *Node.js* is used to both start a simple web-server but also runs the optimizer that minifies and concatenates the codebase. Node.js is a platform that is built for creating network applications and is often used in data-intensive real-time applications.

This makes up the prototype architecture which can be represented by the following model:

![Model showing the prototype architecture.](image)

Figure 4.1: Model showing the prototype architecture.
4.2 Prototype design

The design of the prototype underwent several cycles. The first began with an initial meeting with the external supervisor which elicited the initial requirements. These were as follows:

- The application should allow the user to change between representation and simulation (by using a gesture for example).
- There needs to be a configurability aspect to the prototype (there only needs to be shown what is relevant to complete task).
- Load and save states or save features for keeping track of the users progress.
- The application should provide the user with meaningful quantitative input values for the behaviors.

Additionally, the basic behaviors needed for modeling in the chosen knowledge domain of astronomy, and more specifically, a simplified model of the solar system were elicited (essential basic behaviors were also listed, denoted in brackets):

- Name - used to assign names of elements.
- Type - used to give the element a type.
- Move - in either X or Y, with a specific value for each direction.
- Turn - in a specific direction, angles preferably.
- (Rotate) - the element rotates around its own axis.
- (Circle) - the element circles another element.

With the initial requirements in mind the design process started with basic sketches and scribbles, see Appendix B, which were revised together with the supervisors, until a basic interaction design was made digitally, see Appendix C. Upon doing this the first version of the interface was created with simple functionality was implemented like free drawing, selection and manipulation see figure 4.2.
The subsequent version included more functionality and a redesign. The functionality that was included allowed the user to perform the previous tasks but also actions such as: grouping/ungrouping, undo/redo, clear the canvas, save their progress, assign behaviors to grouped elements (see Figure 4.3).

Figure 4.3: SimPad prototype showing how to assign behaviors to a drawn element
Additionally, this version allowed the user to simulate their model in a simulation view which has simple play and pause controls. (see Figure 4.4).

![Figure 4.4: Simpad digital prototype](image)

In summary, the prototype design consists of two separate views: the modeling/drawing view and the simulation view. The modeling/drawing view has a, by default, hidden behavior panel which is shown when the user interacts with a grouped object. It also holds the tool panel which is always visible to the left when in the modeling/drawing view. The simulation view only allows for the simulation of the users drawn model and interaction with the drawn objects is inactivated in this view.

The version described above was then evaluated with the representative end-users as it incorporated the initial requirements and functionality necessary to allow for a DBM experience in the knowledge domain of the solar system. The results of testing with the end-users are discussed in the following chapter, followed by a discussion and conclusion.
Chapter 5

Results

In this chapter, the results of this research is presented. The results from the prototype evaluation and subsequent analysis are presented in the following section. The chapter ends with a summary of the results.

5.1 Evaluation results

This section will describe the results from evaluation of the prototype which was conducted with 8 children in the ages between 10 and 11-years old at a middle-school in southern Sweden. Participants willing to participate were asked to refer to their legal guardians to fill out an informed consent form. This form outlined what the purpose of the research and assured the participants anonymity but also allowing the participants to be recorded with video during the testing.

The evaluation was carried out in three ways. The first being questionnaires that participants of the evaluation were asked to fill out before testing the prototype (pre-test) and also one after the testing (post-test) as well as a questionnaire about their experience with the prototype and their own perceived performance. Second, a usability test was performed where the participants performed a main task that was divided into several sub-tasks. This process was recorded with video. Lastly, the video was analyzed using a Flow Chart and Significant Events as proposed by Ash [53].

This section is divided into three sub-sections that will present the results for the pre- and post-test questionnaires (Section 5.1.1), the motivation questionnaire (Section 5.1.2) and lastly that of the usability test video recording analysis (Section 5.1.3).
5.1.1 Results from pre- and post-test questionnaires

The participants answered two identical pre- and post-test questionnaires (see Appendix E) before the testing of the prototype and after. This was done in order to gauge the participants knowledge about the domain they were modeling in, but also to provide data for comparison after the participants had used the prototype.

The results from the questionnaires show no significant variance between the pre- and post-test questionnaires and the majority of the participants answered all of the 7 questions correctly in the pre-test questionnaire. However, in the post-test questionnaire 3 participants chose incorrect answers, and the same incorrect answers from the pre-test remained.

5.1.2 Results from participant motivation questionnaire

After the testing session was completed the participants were asked to fill out a motivation questionnaire which measured their competence, how they valued the task and if they found the task useful. The participants were Swedish middle schoolers in the ages between 10 and 12 years old. The grading scale for the questionnaire consisted of four options, where 1 = Totally disagree and where 4 = Totally agree.

The results of this questionnaire is shown in Table 5.1 on the following page.

The results show that the participants found the task interesting (Q2), and that they enjoyed working with the application (Q4). However, the participants also found the application difficult to work with (Q5) but still thought that the application helped them understand the solar system better (Q10) and that the application can help them understand other phenomena better (Q11).
<table>
<thead>
<tr>
<th>Question no.</th>
<th>Question</th>
<th>Most freq. answer</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>I have worked with a similar tablet application before.</td>
<td>Somewhat disagree</td>
<td>2</td>
</tr>
<tr>
<td>Q2</td>
<td>I found this drawing task interesting.</td>
<td>Totally agree</td>
<td>4</td>
</tr>
<tr>
<td>Q3</td>
<td>I did not like to think about the solar system.</td>
<td>Totally disagree</td>
<td>1.5</td>
</tr>
<tr>
<td>Q4</td>
<td>I liked to work with this application.</td>
<td>Totally agree</td>
<td>4</td>
</tr>
<tr>
<td>Q5</td>
<td>I found it difficult to work with this application.</td>
<td>Somewhat agree</td>
<td>3</td>
</tr>
<tr>
<td>Q6</td>
<td>I think I created good drawings.</td>
<td>Totally agree</td>
<td>3.37</td>
</tr>
<tr>
<td>Q7</td>
<td>The drawing task helped me to better understand the solar system.</td>
<td>Somewhat agree</td>
<td>3.12</td>
</tr>
<tr>
<td>Q8</td>
<td>I liked to see how the drawings were moving.</td>
<td>Totally agree</td>
<td>3.71</td>
</tr>
<tr>
<td>Q9</td>
<td>I found it difficult to get the drawing to move.</td>
<td>Somewhat agree</td>
<td>2.75</td>
</tr>
<tr>
<td>Q10</td>
<td>I understand the solar system better after I watched the drawings.</td>
<td>Somewhat agree/Totally agree</td>
<td>3</td>
</tr>
<tr>
<td>Q11</td>
<td>I think the application can help me to understand things better.</td>
<td>Somewhat agree</td>
<td>3.12</td>
</tr>
<tr>
<td>Q12</td>
<td>Letting the drawing move has helped me to understand the solar system.</td>
<td>Somewhat agree</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Table 5.1: Results from motivation questionnaire
5.1.3 Results of video analysis from usability testing sessions

While performing drawing-based modeling each participant was recorded with video. The recording consisted of roughly 2 hours of material which was edited down to around 50 minutes of material. This subsequent edited video was then analyzed by using a Flow Chart, which provided a rough overview of the different participants and how long they each spent on the tasks. This chart was then further broken down into Significant Events (SEs). The results of this analysis is presented in Table 5.2 on the following page.

The results from the video analysis show several key issues with the interaction design of the application. Firstly, participants had trouble distinguishing what tools was currently active (SE1-2 & SE7). Participants also had problems selecting, and specifically grouping drawn objects (SE2, SE6, SE8, SE15). Some participants also found that manipulating their drawn objects problematic (SE11-14). Lastly, which is not illustrated in the table since all the participants behaved the same way, is how the participants they handled the feedback from the application. For example when the participants cleared the all the drawn objects or when they tried to simulate without assigned behaviors. The modal popups that the application showed containing appropriate feedback were dismissed by all users instinctively without reading them. The issues presented in this section forms the basis for proposing ID guidelines and also ID affordances that are presented in the following section.
<table>
<thead>
<tr>
<th>Event no.</th>
<th>Participant no.</th>
<th>Description</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1</td>
<td>P02</td>
<td>Trouble distinguishing of what tool is active</td>
<td>07:47</td>
</tr>
<tr>
<td>SE2</td>
<td>P02</td>
<td>Trouble using selection tool and grouping</td>
<td>08:02</td>
</tr>
<tr>
<td>SE3</td>
<td>P02</td>
<td>Participant decides to start over again.</td>
<td>08:30</td>
</tr>
<tr>
<td>SE4</td>
<td>P02</td>
<td>Participant still has trouble using the selection tool</td>
<td>08:50</td>
</tr>
<tr>
<td>SE5</td>
<td>P02</td>
<td>Participant finds the slider tool hard to use</td>
<td>09:20</td>
</tr>
<tr>
<td>SE6</td>
<td>P03</td>
<td>Participant does not understand selection of elements</td>
<td>11:50</td>
</tr>
<tr>
<td>SE7</td>
<td>P03</td>
<td>Participant finds trouble switching between tools</td>
<td>13:05</td>
</tr>
<tr>
<td>SE8</td>
<td>P03</td>
<td>Yet again, participant shows problems understanding how to group drawn elements</td>
<td>13:30</td>
</tr>
<tr>
<td>SE9</td>
<td>P03</td>
<td>Participant gestures drawing the earth and how it will rotate just before drawing it in the air</td>
<td>14:20</td>
</tr>
<tr>
<td>SE10</td>
<td>P03</td>
<td>Participant states that selection is kind of tricky</td>
<td>15:00</td>
</tr>
<tr>
<td>SE11</td>
<td>P04</td>
<td>Participant is notably concerned with drawing a lot of details in drawing. Has a hard time making minor adjustments</td>
<td>18:40</td>
</tr>
<tr>
<td>SE12</td>
<td>P05</td>
<td>Participant draws large object and realizes there won’t be enough space to draw more.</td>
<td>27:10</td>
</tr>
<tr>
<td>SE13</td>
<td>P05</td>
<td>Participant is told that pinching gesture works, doesn’t seem intuitive.</td>
<td>27:15</td>
</tr>
<tr>
<td>SE14</td>
<td>P06</td>
<td>Participant finds the behavior-menu somewhat in the way when moving objects.</td>
<td>34:40</td>
</tr>
<tr>
<td>SE15</td>
<td>P07</td>
<td>Participant also appears to have issues with the selection and grouping of objects.</td>
<td>38:32</td>
</tr>
<tr>
<td>SE16</td>
<td>P07</td>
<td>Participant has trouble understanding how to assign the target of a circle behavior</td>
<td>42:25</td>
</tr>
<tr>
<td>SE17</td>
<td>P08</td>
<td>Participant also conceptualizes with hands by “drawing” in the air, when explaining celestial orbits</td>
<td>47:46</td>
</tr>
</tbody>
</table>

Table 5.2: Video analysis results
5.2 Summary of results

This section summarizes the results presented in this chapter and proposes ID guidelines (Subsection 5.2.1) and affordances (Subsection 5.2.2) for NUIs to allow for DBM on tablet devices. This is done by looking at the combined results from the questionnaires and video analysis in relation to the current guidelines.

5.2.1 Proposed interaction design guidelines

First, it is necessary consider the existing guidelines from the major device manufacturers as seen in (Section 2.2) before proposing a new set of guidelines. The existing guidelines are as follows:

1) Design for direct manipulation
2) Utilize gestures
3) Provide meaningful feedback to the user
4) Be consistent in the UI

These are then related to the significant events that were identified from the video analysis in Section 5.1.3, which shows several interaction issues. The issues can be summarized as the some participants showing difficulty choosing between tools, making selections and groups, manipulating drawn objects, and not reading modal feedback popups. With these in mind, the following additional ID guidelines for NUIs to have DBM are proposed:

1) **Vital functionality should be made visible at all times.**
   As a way to address the issue of the participants not knowing what tools that was currently being used. Some participants also had trouble understanding how to make the panel that held the inputs fields for the behavior for a grouped object to appear (SE14 and SE16 in Table 5.2).

2) **The selection and grouping of drawn objects should be intuitive (if possible automatic).**
   A common issue that this guideline addresses is selection and grouping. The process of selecting several drawn objects and then grouping those objects showed to be counter-intuitive (SE1-2, SE4, SE6-8, SE10, SE15 in Table 5.2).
3) **Decide on one way to allow for object manipulation (gestures or on-object controls) to avoid confusion.**

Another issue that was identified with SE12-13 was the way participants manipulated objects. Most participants utilized the on-object control-handles for resizing their drawn objects rather than the pinch gesture and when the gesture was shown it seemed to confuse more rather than aid them.

4) **Consider they way of showing feedback, modal popups tend to be dismissed without concern.**

As previously stated, all participants ignored the modal feedback popups that appeared during use of the prototype (for example when clearing the drawing area or when trying to simulate without assigned behaviors).

### 5.2.2 Proposed interaction design affordances

The ID affordances that come with an NUI for DBM were identified through the participants interactions with the prototype in the recordings. The affordances stated here relate to the definition of affordances used in this research namely: the qualities of an object, or environment, that allows a person or user, to perform a specific action. For this research the identified affordances are as follows:

1) **Selectability**

   A key factor that the result have shown through the video analysis is the issue with how the user should select their drawn objects on the drawing canvas. This should be intuitive and not become an obstacle for the user.

2) **Groupability**

   The results also showed an issue with the process of grouping drawn objects. The grouping is fundamental to DBM as it allows for the software to assign behaviors to the grouped object.

3) **Manipulability**

   Another factor is that of being able to manipulate the currently selected object. Whether it be its size, rotation or other properties, it should be easily achieved.
5.2.3 Takeaways from summary

In summary, the findings show both the potential of the prototype, but also the limitations of it in terms of the interaction design. The findings show that while offering users new ways to investigate scientific phenomena such as the solar system, it also shows that this type of interface has certain affordances that allow for a drawing-based modeling experience on tablet devices. The proposed affordances could also be applicable in a wider setting, as in not specifically for drawing-based modeling. In such an event the affordances will likely be expanded to cover other aspects. However, the affordance manipulability seems the most transferable.

Interaction designers looking to either build upon this research or create similar interfaces should be aware of these affordances as they are fundamental to the tablet-based drawing-based modeling experience. In addition to this a proposed set of interaction design guidelines can where identified that can guide the design of these types of interface for drawing-based modeling on tablet devices. The following chapter will discuss these proposed guidelines and affordances.
Chapter 6

Discussion and conclusion

This chapter will discuss the importance and implications of the findings from the research and puts it in the context of existing theory and previous research. Additionally, the limitations of the methodological approach to the research will be addressed. Following this comes the conclusions, and lastly avenues for future work.

6.1 Discussion

With the advent of new technologies such as multi-touch tablet devices comes potential benefits for learning. This research investigates the identification of potential guidelines for the interaction design of tablet-based natural user interfaces, specifically for drawing-based modeling. This research has designed, developed a web-based prototype that was evaluated with eight Swedish middle-school children. In the subsequent sections the results are related to the research questions, plans for future work is outlined and conclusions that can be drawn from the research is presented.

6.1.1 Addressing the research questions

RQ1: What new interaction design guidelines can be identified for the creation of a natural user interface for drawing-based modeling on tablet devices to support science education?

In order to address this question the research has reviewed current interaction design guidelines from the major device manufacturers Apple, Google and Microsoft. Further, the aspect of device ergonomics showed to have impact on the way the user interacts with the device. Through iterative cycles of design the prototype design evolved from sketches to digital version with basic functionality and subsequently a
testable prototype. Because the prototype was to ultimately be used in a classroom setting with children of a known demographic, the design process could have greatly been improved by involving these potential end-users throughout the design-process. This could attest for the results of the motivational questionnaire which shows that 50% of the children that worked with the prototype found it difficult to work with. However, the questionnaire data must be interpreted with caution because of the small sample size. But also because it uses of a four point Likert scale, which produces more extreme values as it eliminates the neutral choice alternatives in Likert-scale questionnaires.

Additionally, the term of NUIs still remain a relatively fuzzy concept. Because of this, identifying potential guidelines for the creation of such interfaces becomes a difficult undertaking. Arguably, the clear distinction between WIMP-interfaces and NUIs cannot be made so easily, if not only through "touch input" or "gestures". This is because NUIs also introduces the complexity of multimodal inputs, referring to the combination several input modes, for example speech, touch, gaze, and gestures [8].

By considering the existing guidelines and through video analysis, the results in Section 5.2 show proposed initial ID guidelines for NUIs to have DBM. These guidelines were primarily generated through the identification of the most common issues that the participants had when using the prototype. These guidelines should be regarded as initial and will most likely be refined as the prototype goes through additional iterations of design.

RQ2: What are the interaction design affordances that come with an NUI for drawing-based modeling?

To answer this question it is necessary to address the definition of an ID affordance. In this research, an ID affordance is defined as the qualities of an object, or environment, that allows a person or user, to perform a specific action. It should be noted that while this definition gives a basis for investigation, it is too generic for most HCI researchers or ID practitioners and will likely generate a number of questions as to what type of affordances that is investigated. An alternative, way of investigation would be through what Norman [59] calls signifiers, which would describe what an object is for, what is happening, and what alternatives that are available [59].

By utilizing Ash’s [53] way of performing video analysis it was possible to identify significant events throughout the testing session. Each participant was recorded with video, along with the tablet screen. In the editing process these sources were combined in order to observe the participants reactions as well as, more clearly, what was occurring on the tablet device simultaneously.
The resulting affordances are similar but have been deliberately separated into separate items. This is due to the importance of each of the items for DBM. For example, most of the participants found selection to be a problem when using the prototype. Some of the participants understood that they needed to select what they had drawn but did not fully understand how they would go about doing so. Additionally, after having made a successful selection, the grouping of one or several drawn elements also posed problems for the participant. Although the prototype might have had issues in that regard, it became clear to the participant that they needed to do this on the other drawn elements in order to create a model. Lastly, the manipulation of the drawn elements also played a factor. Despite having access to the gestures of pinching and rotating with two fingers on an iPad, most of the participants seemed to rely on the manipulation-elements that were shown on a selected element.

**RQ3**: What potential learning benefits can an NUI for drawing-based modeling provide?

This research question was investigated through the combination of the questionnaires and the video-analysis. The results from the questionnaires show that despite 50% of the participants considering the prototype to be hard to work with, all of the participants enjoyed working with the prototype and 87.5% think they can learn more about concepts with the prototype. Again, these results need to be carefully considered as the sample size is apt for usability testing but not for statistical significance nor can the pre- and post-test questionnaires be used for measuring knowledge gain. However, as this research has explained in the scope and limitations, the investigation of knowledge gain is beyond scope. In this research the pre- and post-test questionnaires were merely used as to investigate if there were any major differences in the results after the participants had used the prototype.

### 6.1.2 Prototype applicability

As the prototype that was developed and designed in the research in this thesis was specifically targeted toward one domain, namely the solar system, the wider relevancy of the prototype for other demographics should be discussed. Despite the prototype seemingly having a simple interface that is specifically designed for only one domain, this is not the case. The interface is extensible enough to allow for the addition, or removal, of different types of behaviors and tools. Additionally, the prototype itself could be targeted towards older users, provided that the behaviors that are to be implemented are complex enough.
6.2 Conclusions

The objective of the work in this thesis has been the design and development of a web-based tablet application with a natural user interface as means to identify interaction design guidelines for the development of similar drawing-based modeling tools on tablets. Further, the research was also tasked with identifying the affordances of the interface and investigate its potential to support learning.

In conclusion, the research has designed, developed and evaluated a prototype web-based tablet application for drawing-based modeling. Additionally, guidelines and affordances for interaction design of natural user interfaces for drawing-based modeling have been proposed. Moreover, through evaluation with representative end-users and questionnaires it is shown that the prototype can support learning, but that it also should be explored with teachers and their students.

The proposed guidelines in this research can be valuable for interaction designers that are concerned with designing natural user interfaces for drawing-based modeling, specifically for tablet devices. These designers should consider the visibility of vital functionality, and the intuitiveness of the selection and grouping of drawn elements - consider doing it automatically, and choosing one way of object manipulation, and lastly how to properly present feedback to the user.

When designing and subsequently testing such an interface the designer should also be aware of the identified affordances in these types of interfaces. Namely, selectability, groupability, and manipulability.

Designers or researchers can continue the evolution of SimPad through the iterative design-based research cycles, or create other tools to enable drawing-based modeling, perhaps based on the guidelines and affordances proposed in this study. Ultimately, the possibilities of these devices in learning are still in their infancy. There is a need for additional research and tools in order to fully investigate their future role in the classroom.
6.3 Future work

The current investigation was limited in regards to the prototype. There are several possible venues that researchers could expand upon through future work. Firstly, the different behaviors that are available in the current prototype are limited. The prototype therefore becomes restricted in its capability to create different models in other knowledge domains.

Additionally, for the prototype to actually be used to gather scientific data on the user’s actions during use need to be improved. This way the prototype could be used to collect user data during the user’s session. For instance, the data could be stored in a relational database. However, for data separation the need for user management such as registration and login/logout would need to be implemented.

Moreover, the current prototype only considers one type of user namely the learner. Future work might investigate the aspect of the teachers role and how they would utilize a DBM tablet application in curricula. This would impose new requirements on the prototype and would necessitate evaluation with this type of user group as well, preferably in a natural environment.
Bibliography


[33] Y. Mor and N. Winters, “Design approaches in technology-enhanced learning,”

[34] A. Brown, “Design experiments - Theoretical and methodological challenges
in creating complex interventions in classroom settings,” The journal of the

2012.


[37] H. Hallerström, “En egen dator som redskap för lärande Research Report in
Sociology of Law som redskap för lärande,” Sociology of Law, Lund University,

[38] Chitika, “February Tablet Update: Usage of Android Tablets Again

selection, and summarizing as learning strategies,” Learning and Instruction,

ings to support modelling in science education,” British Journal of Educational

[41] T. Joolingen, W.R. van, & Jong, “SimQuest, authoring educational simula-
tions,” in Authoring Tools for Advanced Technology Learning Environments:
Toward cost-effective adaptive, interactive, and intelligent educational software,


Appendix A

DSRM process model

![Diagram of the DSRM process model]

Figure A.1: Peffers et al. suggested process model for design research (taken from [1])
Appendix B

SimPad sketches

Figure B.1: Showing SimPad paper sketches
Appendix C

SimPad interaction design flow
Appendix D

SimPad usability questionnaires (in Swedish)

<table>
<thead>
<tr>
<th>FRÅGEFORMULÄR “SOLSYSTEMET”</th>
</tr>
</thead>
</table>

**DEMOGRAFI**

<table>
<thead>
<tr>
<th>År du en kille eller tjej?</th>
</tr>
</thead>
<tbody>
<tr>
<td>________________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vilken skola går du på?</th>
</tr>
</thead>
<tbody>
<tr>
<td>_______________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hur gammal är du?</th>
</tr>
</thead>
<tbody>
<tr>
<td>__________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FRÅGOR OM SOLSYSTEMET (RINGA IN DITT SVAR)</th>
</tr>
</thead>
</table>

1) Vad består solsystemet av?
   a) Av alla befintliga stjärnor sammanlagt.
   b) Solen och planeterna, som vänder sig runt solen.
   c) Solen, jorden och månen.
   d) Av några få stjärnor.

2) Vad är jorden?
   a) En planet.
   b) En stjärna.
   c) En måne.
   d) En liten sol.

3) Vad cirkulerar jorden runt?
   a) Jorden cirkulerar runt solen.
   b) Jorden cirkulerar runt månen.
   c) Jorden cirkulerar inte runt någonting, men månen och solen cirkulerar runt jorden.
   d) Jorden cirkulerar inte runt någonting, men solen cirkulerar runt jorden.

4) Vad är solen?
   a) En satellit.
   b) En planet.
   c) En måne.
   d) En stjärna.

5) Vad cirkulerar solen runt?
   a) Solen cirkulerar runt planeterna.
   b) Solen cirkulerar runt jorden.
   c) Solen cirkulerar tillsammans med månen runt jorden.
   d) Solen cirkulerar inte någonting.

6) Var är solen på natten?
   a) Solen är bakom månen.
   b) Solen är på andra sidan jorden.
   c) Moln skymer solen.
   d) Stjärnorna är i vägen för solen.

7) Hur kommer det sig att solen rör sig över himlen varje dag?
   a) Jorden roterar kring sig själv.
   b) Solen rör sig helt enkelt över himlen.
   c) Jorden cirkulerar runt solen.
   d) Solen roterar runt sig själv.
Appendix E

SimPad usability questionnaires (in Swedish)

<table>
<thead>
<tr>
<th>Fråga</th>
<th>Håller inte med alls</th>
<th>Håller inte med något</th>
<th>Håller med något</th>
<th>Håller helt med</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jag har arbetat med en liknande tablet-applikation innan.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag tyckte denna ritningsuppgift var intressant.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag gillade inte att tänka på solsystemet.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag gillade att arbeta med denna applikation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag tyckte det var svårt att arbeta med denna applikation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag tycker att jag skapade bra ritningar.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Att rita hjälpte mig att förstå solsystemet bättre.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag gillade att se hur det jag ritade kunde röra på sig.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag tyckte det var svårt att få ritningarna att röra på sig.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag förstod solsystemet bättre efter att jag såg ritningarna.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag tror att applikationen kan hjälpa mig förstå saker bättre.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag förstod solsystemet bättre efter att jag såg ritningarna röra på sig.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>