

# Strategies, Practices, and Challenges in Interactive Prototypes Construction: a Field Study in a Design Course

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## ABSTRACT

Prototyping tools are critical to sustaining an iterative prototyping process that is meaningful, adaptable, and efficient. Today, designers continue to face challenges in building, programming, and debugging interactive prototypes of electronic connections and computational systems parts. This fieldwork research investigates, discusses, and examines the practices, tools, and technologies used by design students on a university course to create interactive prototypes. The study investigation examines the interactive prototypes as well as excerpts from student interviews. Our findings shed light on the socio-technical variables that drive digital component selection. The paper covers the practices used by design students to construct them. Our findings suggest that a greater number of prototype iterations may reduce design fixation. Finally, the study's findings and implications are examined.

## CCS CONCEPTS

• **Social and professional topics;** • **Human-centered computing;**

## KEYWORDS

Interactivity, Design, Education, Prototyping Tools, Practices

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## 1 INTRODUCTION

According to Ehn and Kyng, prototypes are key artefacts used in the design of interactive systems [16]. Beaudouin-Lafon and Mackay define a prototype as a concrete representation of part or all of an interactive system [7]. Similarly, Houde and Hill discuss the functions of prototypes, defining the prototype as any representation of a design idea, regardless of medium [21]. In this work, our prototype definition aligned with the earlier definitions, which we define as a manifestation of design ideas that allow designers to explore the design space. Similarly, Buxton [12] emphasises the significance of

sketching through prototyping, and Buchenau and Suri describe the experience prototyping method [11]. Our research defines prototyping as a socio-technical process undertaken by designers and other stakeholders to elaborate and transform design concepts into prototypes. The prototyping methods and tools are essential to support designers in exploring and programming the prototype design space. Grigorenu et al. [17] identify the main areas designers need tools and support for creating, iterating and communicating. Other researchers present categories and challenges for different types of prototyping tools [3, 13]. A survey study by Meyers et al. [24] provides further insights by identifying interface design tools and the difficulties in using these tools to express and communicate interactive behaviours.

However, these studies have contributed to the interactive prototypes and prototyping literature. Still, more is needed to know about how design students construct physical-digital interactive prototypes in practice. Expanding the research topic will advance the development of enhanced design tools which are effortlessly integrable into actual design practices and contexts [25, 26]. In this study, we present the results of a fieldwork study that investigated how design students constructed interactive prototypes in a final-year university design course. This research aimed to yield detailed insights into how design students create interactive prototypes in practice. The study examined interactive prototypes, technologies, and student practices to understand how designers connect hardware and software components. The study also aimed to describe and analyse which electronics and software components and technologies were used. Our contribution highlights the need to redesign prototyping tools to better support the processes between people and artefacts during problem-solving tasks related to prototyping. The research was motivated by three specific questions:

- How do design students select digital components for prototype construction, and what criteria influence their decision?
- In design educational situations, how do design students develop interactive prototypes with those components?
- What methods are used to determine the components of interactive prototypes and user interactions?

## 2 RELATED WORK

A consistent body of literature comes from the reports on designers' and researchers' challenges met while building interactive prototypes. For example, recent research describes the form factor and interaction reliability challenges of designing small embedded tangible artefacts for children with off-the-shelf prototyping technologies [2]. Hazlewood [20] described, in a case study, the complex strategies for actuators and sensors connections and the complex component choices strategies due to the intrinsic components' qualities and location and context challenges, faced in

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designing a large-scale interactive installation. Another study explored the design challenges, issues, and limitations for designers and researchers in constructing Internet of Things systems using existing prototyping tools [4, 5]. The present research helps further clarify the reasons for these challenges and how they are resolved.

Interactive prototypes are a blend of various tools and components. According to recent research, design students use simple hardware components (e.g., buttons) to scaffold the development of their prototype online data exchange with the Internet [6]. A study by Klemmer and Landay [22] to inform the design process of the Papier-Mache toolkit present the difficulties programmers encountered in designing and developing physical-digital interactive ubiquitous systems. For example, the study highlights that programmers create the relationships between the physical artefacts and the corresponding digital entity in a 1:1 ratio. The study also shows that designers preferred to use components with multiple communication possibilities (e.g., serial communication) to facilitate the interactive prototype construction. As Hartman et al. [18] demonstrated, solutions for connecting the various interactive prototype components may come from a field quite different from the area in which the prototype is developed. The same research shows that the web and the communities of practice were quite influential in searching for these “bridges”. The study also indicates that experienced designers’ search has better results than non-expert designers. However, these studies show how people make interactive prototypes; they do not specify the challenges of how prototype construction happens.

Debugging software and hardware physical and digital prototypes is very complex [22]. The difficulty comes from several factors; for example, software and hardware processes during debugging are invisible and require higher cognitive efforts for programmers or designers [1, 14]. Several tools have been developed to support user interfaces designers and software programmers to debug their software [27]. However, the development of physical-digital prototyping tools has not reached this high level of support. A recent empirical study on physical computing tasks shows that circuit problems cause more failure than program problems, and 80% of failures are due to missing wiring, independently from the subject’s expertise [8]. According to Brandt [10], programmers use the web massively during debugging activities. Other debugging strategies on various software and components assembly, programmers used several methods to visualise process flows, for example, using several print statements on their prototype’s codes [9]. Despite all these studies, there is still little understanding of prototyping practices in physical-digital interactive prototyping. These studies lack clarification of why these challenges occur. Our work will be an initial effort to fill this literature gap on how design students prototype prototypes in educational settings. Our study analyses individual students’ prototyping activities in a design course to highlight the interactive prototyping challenges and their solutions. This study explains prototyping troubleshooting strategies and dynamics ‘in the wild’, informs the design of new prototyping tools that make the most of these dynamics, and provides insights for educators and instructors.

### 3 METHODOLOGY

In this section, we describe the study context, the research methods, and the data analysis method conducted with design students in a final (fourth) year course on design at the Design Department at the University of Dundee (United Kingdom). The Personal Honours project module aims to provide a platform for students to bring together chosen elements they have learned through a personal project. Students produce individual design outcomes for selected project briefs, drawing on their knowledge and skills developed throughout the program. Students can access a faculty workshop, digital fabrication lab, and IT suite. They also get support from design studio specialists and workshop technicians. The class is organised as a studio, where each student has their area, sharing their learning experience in the same studio space. The aims of the projects in the course were to create interactive artefacts which could respond to the user needs, which emerged during the students’ users’ research. The class comprised product design (PD) and interaction design (IxD) students. Both interaction and product design students have a shared class on Arduino and Processing during their second year. The module tutors and teachers have a background in product design, interaction design, design engineering, and human-computer interaction. When they reach the fourth year, all the students have two years of digital prototype experience, mainly with Arduino and Processing.

During the study, we used semi-structured interviews with students and prototype analyses. For the semi-structured interview, we designed seven questions, which the researcher used to start the discussion about their prototype development. Questions were developed to explore the projects’ technologies and tools, development solutions to issues related to technology composition, and their level of expertise with the used technologies and tools. The researchers also asked each interviewee to sketch a functional representation of the system on paper, highlighting the methods used to connect the different components. The interview participants were self-selected from the design class. We contacted the fifty-seven students via e-mail, nineteen of whom agreed to be interviewed. The participants ranged in age from 23 to 27 years; eleven were male, and eight were female. They had an average of two to three years of experience building interactive prototypes. The same procedure and interview schedule were adopted in all interviews. A single face-to-face interview ranging from 40 minutes to two hours was conducted with each interviewee. All interviews were video-recorded with the participants’ permission, and the researchers took written notes. The semi-structured interviews were conducted in the design studio.

After concluding the data-gathering process, we began elaborating on the collected data. All the video and audio data coming from the interview were transcribed and organised by participants. We collect more than 27 hours of interviews with students. The data were consequently printed, read and initially commented by researchers. We conducted an interview analysis focusing on thematic coding. During the coding researcher attached one or more keywords to a text segment to permit later identification of the statements. We coded specific acts, behaviours, events, contexts, activities, strategies, practices or tactics, etc. We didn’t start with codes in mind developed in advance; instead, we used data-driven

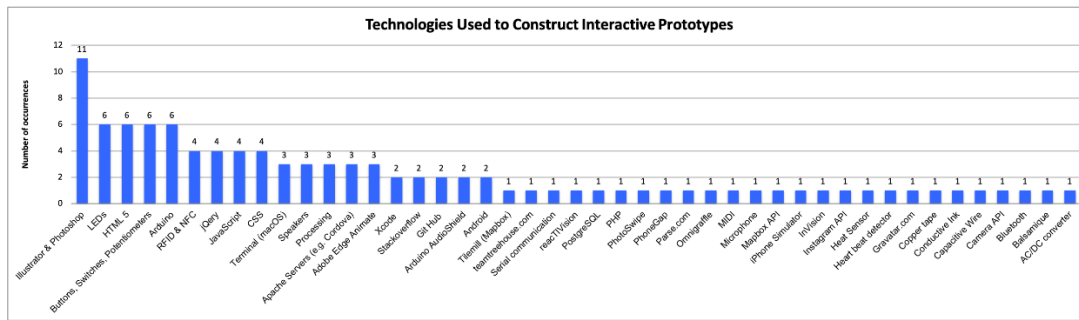


Figure 1: List of technologies for prototypes construction and their occurrences

coding, which implies that we started without codes and developed them through reading the material. Examples of codes were: mapping inputs; LED strategy. Consequently, we aggregate the coding, developing categories that capture the whole experience studied. We reduced coding into categories making it possible to quantify how often specific themes were addressed, and the frequency of themes can then be compared and correlated with others. Categories examples were: technology learning; simplification process. The data instances were constantly compared for similarities and differences. During the analysis phase, we moved from descriptive to more theoretical levels leading to a saturation of the material insight and interpretation. All the data were aggregated and discussed with researchers. We highlighted the more important study results and topics that could contribute to expanding the research literature in the field. In the next section, we will elaborate on the study results.

## 4 PROTOTYPING INTERACTION PRACTICES

In the fieldwork study, we observed that the design students used a broad and rich range of practices to connect components and overcome technical problems that emerged during the prototype development.

### 4.1 Factors Influencing Technologies Choice

During the course, the design students explored the prototyping technologies and tools within three main prototype interaction phases with a duration of about three to six weeks each: mark one (Mk I), mark two (Mk II), and the final prototype. During the early design concepts generation phase, the course tutors encouraged the students to think about the technologies and tools they would use to develop their interactive prototypes. Factors like familiarity, efficiency, security, compatibility, dimensions, and costs, were essential for students in choosing technologies and tools for their prototypes (Fig. 1). Popular technologies and tools for prototypes were Arduino, Processing programming language, basic sensors, and simple actuators, HTML5 & CSS.

### 4.2 Reverse engineering and design fixation.

In design, reverse engineering is a common method for problem-solving and idea generation. In reverse engineering, process designers extract knowledge and information from analogously produced

artefacts. During this information discovery process, design students disassemble and analyse products to get insight for their project. In the reverse engineering processes, students examine to deduce design features from products. Reverse engineering is an excellent way to get insights, but sometimes, it may harm the process fostering the design fixation.

For example, a product design student worked on a project to face the problem of access to electricity for people living in Africa. The student described that he chose his technology by looking at similar products and disassembling them to understand their inner workings. The students took as an example a shaker light, which charges by shaking them, making the internal magnet pass through coils to charge batteries. As described by the student:

*"You know the shaker lights charge so quickly. The idea there is a magnet you shake off the magnet goes through the coil here it passes through,"* he continued, *"because I was looking completely from the wrong direction, I think, originally I was trying to get the magnets to pass through the copper spindle to generate electricity, instead of de-touching the power source to the flywheel I want to be"* (A16).

The reverse engineering process may be a good and powerful approach to inspiration. Still, as reported by the student, this process could narrow the early project vision, with the risk of remaining too fixed on the inspiring artefacts. The student produced a higher number of prototype iterations (>15) compared to the classmates. The high iterative process permitted the student to release his initial design fixations from the shake lamp disassembling process. That suggests that the number of prototype iterations may play a fundamental role in mitigating the design fixation caused by the reverse engineering process.

## 5 DISCUSSION

This fieldwork study aimed to identify challenges and practices encountered by design students constructing interactive prototypes in a final-year university design course. The fieldwork combines prototype analysis and semi-structured interviews.

Our findings show that popular technologies and tools were Arduino, Processing programming language, basic sensors, and simple actuators, HTML5 & CSS. Our study indicates that high prototype iterations may benefit students' component choices influenced by design fixation dynamics derived from reverse engineering insights processes. Our results on tools and technology choices in

educational contexts aligned with other researchers exploring prototyping tools and technology choices in professional contexts [23]. Choosing tools and technologies close to the prototype tasks at hand, as reported by Buchenau et. al. [11], is similar to our results showing that design students tend to remain anchored to known tools and technologies. These students' behaviours change only if the support technicians suggest new tools or technologies. Similar to our results for educational contexts, other researchers, [19], highlighted the values and benefits of technologies and tools choice consultancy in professional contexts. Having tools and technologies ready at hand early at the beginning of the design process stimulate students thinking and problem-setting. Representations and actions performed on objects scaffold thinking and reasoning during problem-solving tasks [1]. The students may remain anchored to tools and technologies seen in similar projects because cognitive fixation [15] prevents the students from seeing others uses. The prototype iterations may gradually shift the problem setting and reveal novel unseen solutions. These results may suggest interesting implications for designing novel prototyping tools, educational institutions, and course tutors.

Our study shows that prototyping interactions is a creative activity requiring tinkering and design-thinking skills, but today, most technologies still need to support those processes fully. Design tools require an approach different from engineering. In design, it is fundamental to soften technology to make it quick, imaginative, and easy to shape the user's experience [28]. The road to reaching an easy and entirely understandable technology construction is long, but progress is being made toward the full realisation of easy prototyping interactions. This will allow digital technology to become a significant part of design students' daily lives and provide the required level of user control.

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