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The Role of Prototyping in Design Education

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Abstract

This article will focus on the universal design concept and process with a particular view on prototyping activities. Prototyping is an essential element in design thinking as it translates the design idea into a physical or digital artefact for further evaluation. Hence, prototyping activities can be seen as a connector between understanding design theory and its hands on practical and context rich application using tools and techniques and engaging with an audience to promote the design idea.

The different purposes of employing prototyping during different stages in the design process are explored. The multi-faceted role of prototyping requires design students to not only apply prototyping techniques, but also consider the wider design context in which they are operating in. As such, prototyping is invaluable in its practical relevance for transferring education insights into to business value.

The article also covers the role of designers in various project settings and contexts and conclusions are drawn for the capabilities that will need to be addressed in future design education.

The article will further investigate the role of the ecosystem in which the design takes place with a view on the level of design maturity in an organization and its implications for prototyping. In this context, we will conclude that prototyping is deeply engrained into each design project and often stipulates the tipping point in turning uncertainty into contextual understanding.

Finally, the article will cover learnings from a recent study on design competencies and how different prototyping techniques can stimulate the learning experience for design students.

Keywords

Prototyping, Design, Design Education, Distance Learning

The Role of Prototyping in Design Education

The term "prototype" derives from the Greek terms " protos " (first) and " typos " (shape, model) and describes that something newly conceived is now taking shape for the first time, e.g. in the shape of a physical model. A prototype therefore can be thought of as representing a bridge or transition between the world of thoughts and the "practice test" in real life. The Oxford Dictionary describes a prototype as "the first design of something from which other forms are copied or developed" and therefore alludes to another important aspect of prototyping, namely the fluidity of the concept with the intent to improve over time. Both interpretations are relevant for the current design theory and practice, but the understanding of the role of prototyping and the value it brings to the process is much broader. Next to the notions of describing transition and improving through iteration, prototyping is an essential element in design thinking that fosters evaluation through engaging with stakeholders and particularly users on each phase of the design cycle. This has ramifications for the perspective through which we view a prototype. If a functional perspective is taken, for example, prototyping focuses is on testing the most important functions of a future design and improve them, if required. In this case, the prototype is seen as an object. However, if a design perspective is taken, the interaction with future users is in the focus of the prototype, which produces a very concrete experience with the future system or product

(Yu/Pasinelli and Brem, 2016). This second aspect with a focus on the user experience in design enriches the context for prototyping by including the aspect of evaluation (McElroy, 2016) that can include functional elements, but also the "look and feel" and interactive elements of the design. The International Standard ISO 9241-210:2 further specifies that:

"Iteration should be used to progressively eliminate uncertainty during the development of interactive systems. Iteration implies that descriptions, specifications and prototypes are revised and refined when new information is obtained to minimize the risk of the system under development failing to meet user requirements" (Allanwood & Beare, 2019, p.10).

Finally, McElroy (2016) also describes *prototyping as a mindset of continuous learning and therefore draws attention to the cultural angle of how to translate an idea or concept into a prototype within an organization or ecosystem (McElroy, 2016).*

In conclusion, prototyping goes far beyond the traditional meaning of presenting a functional, almost market ready product for a final review by clients, but instead captures the key elements of the entire design thinking process by provoking mediation, feedback and iteration thereby continuously seeking alignment with user requirements and enabling communication patterns through prototyping that benefits every design-driven organization.

As a result, a prototype can be almost anything: a scribble on a napkin, a wireframe, a spatial model, a service blueprint and as such is a prime example for a low threshold activity enabling design capabilities for all. It is also an activity best learned through experimentation and experience. To benefit from successful prototyping practices, however, a thorough understanding of the thought and analysis process and the design

process itself including its contextual and organizational factors is of key importance and therefore a regular part of the curriculum in design education.

Practical application of the prototyping process

The first learning for design students often occurs at the point when design theory meets business practice, complexity hits and models and frameworks that look straight-forward in a theoretical way, may seem less so during practical implementation. As an example, the Design Thinking Process establishes five stages or design phases. The first phase outlines the problem space and seeks empathy from a user perspective to better understand the problem itself. In the second phase of "define", these insights combined with analysis is compiled, evaluated and synthesized. In the "idea generation" phase – also known as ideation – the design space is opened for various solution and approaches with the final selection of the design or idea that will be pursued. These designs are then translated into artifacts or other prototypes and tested with the appropriate target group.

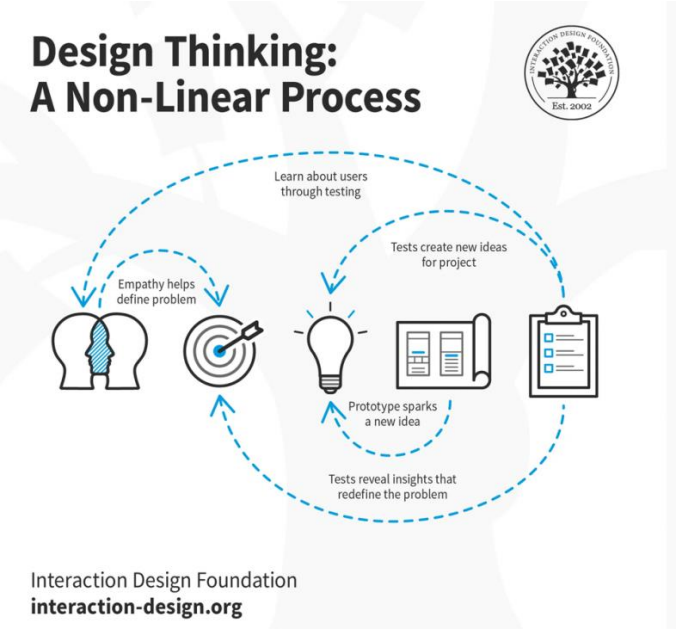

Figure 1: Design Thinking as a non-linear process
Source: Dam, 2021 (URL: https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process)

While prototyping seems to have been allocated a specific place in this model, namely the evaluation and testing phase, prototyping is in fact applied during all stages in the Design Thinking Process. During ideation, prototyping activities help to explore the problem space by considering multiple and alternative solutions. Other purposes prototypes fulfil during the design work cover:

- ***Exploring and Experimentation: The use of prototypes to explore problem space and consider multiple ideas with the intent to test out the potential impact of changes (Dam & Siang, 2021)***
- ***Learning and Understanding: The use of prototypes to comprehend dependencies, dynamics, and options for modification in prototypes (Dam & Siang, 2021)***
- ***Engaging, Testing, and Experiencing: The use of prototypes as communication tools to engage with clients or stakeholders (Dam & Siang, 2021)***
- ***Inspiring and Motivating: The use of prototypes to engage with audience, promote the design idea and motivate or inspire stakeholders (Dam & Siang, 2021).***

This requires student to determine the purpose of each prototyping activity and develop a unique approach that addresses the particular purpose regarding objective, target audience, fidelity, and process. As a result, design students need to develop competencies in the space between formal training and context-richness, an aspect that has been studied in prototyping workshops by Swedish researchers Schaeffer and Palmgren (Schaeffer & Palmgren, 2017). The quality of the prototyping process increases as information is synthesized, uncertainty is reduced and perspectives gained from prototyping participants during multiple iterations that help shape the design to be considering all user preferences and abilities.

The second key learning aspect for design student is that prototyping holds a "bias toward action" (Dam & Siang, 2021), which includes making reasonable assumptions, propelling into activity and meticulously reflecting outcomes of the prototyping effort against set objectives. This also fosters

To enable students to act and adopt a "thinking by doing" mindset is therefore an essential element of any good design education and as a result derives more value from researching, defining, ideating and testing (Dam & Siang, 2021). This implies that design education that covers prototyping ideally needs to include real-life design challenges that can be addressed in a plan / act / reflect learning cycle that focuses on practical learning outcomes.

Going back to the specific prototyping purposes, the specific goals connected to a prototyping effort will differ according to various contextual factors, such as the design approach, project progression, function or the role of the initiator.
McElroy (2016) distinguishes four main goals that prototyping may have in different project phases and constitute a comprehensive summary of all reasons why to prototype (McElroy, 2016). These four main goals comprise:

- ***To understand***
- ***To communicate***
- ***To test and improve***
- ***To advocate***

Therefore, prototyping as a process can be seen as fluid, applying a few key principles, but deploying a discovery mode during its implementation. In relation to this, in their paper Prototypes and Prototyping in Design Research, Wensveen and Matthews (2014) refer to one of four potential roles of prototypes as vehicles for design research that describes the process of prototyping itself as a vehicle for inquiry. In this context, the process of prototyping

becomes a means of inquiry and the process of prototyping focused not so much on the prototype artifact itself and its qualities and dimensions, but instead on the on the process how the prototype was created and how this drives the research direction (Wensveen & Matthews, 2014). Through this process of building, testing, refining and an understanding of the design space is gained and consequently codifiable knowledge about contributing factors such as material selection and material resistance, functional consequences and useful algorithms can be obtained (Wensveen & Matthews, 2014).

Wensveen & Matthews (2014) argue that to implement the role of prototyping as a vehicle for design research, the process of prototyping needs to become an object of analysis (Wensveen & Matthews, 2014), which provides a useful intersection between design practice and design research.

Following this line of thought, Camburn et al. (2017) in their research "Design Prototyping Methods: state of the art in strategies, techniques and guidelines" establish that developing an informed prototyping process considers five primary sections: 1) preparing to prototype, 2) enhancing design prototype performance, 3) reducing design prototype cost, and time, 4) guidelines on fabrication of design prototypes and 5) reflecting on design prototype in science (Camburn, et al., 2017).

The third key learning for design students is therefore to look at the entire prototyping activity holistically, understand the key principles and processes and gain confidence in creating or adapting a particular process to achieve the best possible outcome for their prototyping effort in addition to keep reflecting on the chosen prototyping path throughout the prototyping journey.

How much prototyping is enough?

In their research paper The Anatomy of Prototypes, Lim, Stolterman and Tenenberg (2008) propose two types of

dimensions that are relevant in characterizing prototypes. The first dimension sees prototypes as filters (filtering dimension) through which the design idea is transported (Lim, et al., 2008). The second dimension sees prototypes as manifestations of design ideas (manifestation dimension) that propose approaching the values in this dimension, such as materials, resolution and scope rationally and systematically, and therefore making the case to consider the economic principles of prototyping (Lim, et al., 2008).

The exploration of the dynamics of prototyping economies seeks to understand how the trade-off between gaining additional design information is put into relation to the resources spend in any prototyping effort. This builds on the understanding of prototypes as manifestation of design ideas as proposed by Lim, et al., 2008, which proclaims that "the best prototype is one that, in the simplest and most efficient way, makes the possibilities and limitations of a design idea visible and measurable" (Lim, et. al., 2008).

Prototyping decisions that directly affect project resources evolve around the dimensions of the value, time, cost and fidelity (Tiong et al., 2018). Research has been conducted by Tiong et al. (2018) to understand design principles that support economical prototyping and that include the full complexity of prototyping decision design practitioners face in product development (Tiong et al., 2018). The economies of prototyping as captured in this study consider fidelity (time, cost, effort) as the key input variable and arguably the value in the form of design information gained as the output variable (Tiong et al., 2018). The essence of prototyping economy can therefore be summarized as "how designers choose the cheapest (low cost) way to prototype that is still effective", and hence provides new information gains from the prototyping effort (Tiong et al., 2018).

For design students, the inherent challenge can be summarized by a statement from McElroy (2016) who observes that there is a certain balance between the time and effort that it takes to make a prototype and the corresponding value gain of testing at a specific fidelity (McElroy, 2016).

Unsurprisingly, there is a strong correlation between fidelity and value meaning that prototyping effort with high fidelity usually creates greater value but also entails higher costs in terms of time and cost expenditure (Tiong et al., 2018).

In search of this sweet spot, Tiong's study concludes from the data analysis of 50 distinct prototyping efforts, that four grades of prototyping economies exist (Tiong et al., 2018). This is an important observation for design students to consciously include the greater contextual factors onto their choices for prototyping activities, as would be expected in business life that is constantly being confronted with capacity and resource constraints and the requirements for delivering business cases for project and prototype efforts. In terms of findings Tiong's study concludes with helpful guidelines for the design practitioner to improve the value/fidelity relationship of their prototyping endeavor. These include:

- ***Aim for increased prototype dimensionality and make conscious decisions about which dimension is important for a specific prototype (Tiong et al., 2018)***
- ***Continue to test core concepts with low fidelity prototypes, especially for testing core concepts, basic assumptions and user mental models (Tiong et al., 2018)***
- ***Enrich the value of low fidelity design by leveraging DYI design principles. DYI methods, such as "Hacking" and "Basic Craft" tools that build on already available materials, components, and tools (Tiong et al., 2018)***

- ***Use high fidelity prototypes to answer specific design questions on details and features (Tiong et al., 2018)***
- ***Support physical prototypes with multi-media, such as videos, slides and virtual prototypes (Tiong et al., 2018)***

Regarding the last point, trends indicate that increasingly immersive technologies and augmented reality prototyping , such as VR, AR and mixed reality, are applied to maximize prototyping learning, particularly when applied in the early stages of the design development. Freitas et al. (2020) identified 30 artifacts that facilitate the development of prototypes in AR (Freitas et al., 2020). Their research also revealed that the level of control that can be exercised is also a factor in considering the adoption of immersive technologies, whereby the preference for virtual reality for the creation of prototypes in AR can be attributed to the greater level of control that can be exercised with VR (Freitas et al., 2020). Going forward, this could gain importance when it is required to prototype and test for audiences in the "long tail", that may be hard to achieve in an economic way at the moment.

The increase in prototyping effectiveness will be derived from the reduction of prototyping cycle through use of virtual or augmented prototyping and thus generate positive knock-on effects in reducing costs and time from conceptual design to production and consequently commercialization while also improving the quality of the design (Hall & Takahashi, 2017).

For design students, it is therefore relevant to keep on top of these developments and explore how the value of new technologies can applied into their daily work as a design practitioner with a view on greater inclusion.

Which prototyping tool is the best for me?

The large and to a degree confusing selection of prototyping tools available on the market, poses a challenge in finding exactly the right tool for the purpose at hand. From a design practitioner's

perspective, Warfel (2009) suggests the following considerations as a useful starting point to aid the process of choosing suitable prototyping tools:

- **What is the target group and what is the goal of the prototyping project?**
- **Is there any previous experience with a particular prototyping tool? What is the expected learning curve for the potential users?**
- **How is the current availability of the tools, i.e. pricing model, licenses, subscription choices?**
- **Is timing a constraint, i.e. how quickly is it required to create the prototype?**
- **To what extent is interactivity supported and how complex are the interactivity options?**
- **Which different end devices (tablets, smartphones, but also gesture-based touch screens) are supported by the tool?**
- **Is the transition from the prototype to the real system relevant, i.e. by creating source code or specification documents and how can this be supported by tools?**

(Warfel, 2009)

Further considerations of how the tools would support collaborative efforts among design team members in participatory, collaborative and crowd-based prototyping, would be critical to the entire design prototyping process. Practical aspects would include issues such as parallel work, versioning, publication and commenting functions, the support of multiple designs and different visual fidelity options and the availability of GUI widgets that enables design recycling using existing libraries or creating new ones. (EResult Agency for UX and Usability, 2020).

Therefore, the choice for tools is a complex decision that includes personal preference and organizational context and requirements alike. Regardless, it is useful to equip oneself with a foundational

knowledge of techniques, such as ideation techniques, testing techniques, etc. and build a repository of "tested and tried" methods that cater to diverse prototyping settings and goals. Regarding the selection of technical support tools, Coleman & Goodwin (2017) dedicate a full chapter in their book "Designing UX: Prototyping" to segmenting and categorizing the prototyping tool landscape. The authors build a framework that comprises three groups by which to categorize prototyping tools according to 1) design fidelity 2) tool complexity and speed of use and 3) the aim of the prototype. This provides a helpful navigation of the complex tool landscape and brings orientation to design students trying to achieve multiple goals.

Design students should, however, recognize that knowing and staying on top of the tool landscape, the application of new methods through case studies and realizing the potential of virtual and augmented technologies is a life-long learning process.

Prototyping as a social activity in the organizational context

Re-visiting McElroy's (2016) definition of prototyping as a mindset of continuous learning highlights the importance of the organizational ecosystem and particularly the adoption of design thinking and user-centered design within the organization, which can be a huge contrast to hierarchical and error-focused organizations. The organization's maturity towards the adoption of user experience design has a strong impact on the size and influence of the design team, which becomes evident in the three basic constellations that can be summarized as 1) UX Central Team, 2) Embedded UX Team and 3) UX "One Man Show" (UXpin, n.d.) and may be enhanced by external designers.

Depending on the maturity, designers may have tasks that clearly extend beyond their original scope of doing design work and can

include managerial work, cross-team communication and evangelizing the organization about the business value of design. This enhanced understanding of what design work entails requires student to be trained in handling social situations outside of the design remit and deal with complex situations where design is considered a significant part of a whole (Schaeffer & Palmgren, 2017).

The legendary designer and author Don Norman puts a high emphasis on changing the mindset of design students and to foster this founded the Future of Design Education Initiative together with Karel Vredenburg, Director of design at IBM. Norman states:

***"Designers, traditionally, sit and design something and pass it onto the next stage, then they complain it wasn't done the way they designed it,"* he says. But if they were trained to sit through the whole system, the outcomes would be better. *"Learning the political issues, and economic issues, and divergent views is a critically important thing to getting something done in this world,"* he says. (Brandon, 2021)**

This changing mindset has profound implications for the successful collaboration between designers and developers. Typically, designers are delivering the information about a project and will be explaining context and details to the development team. Considering the different mental models of designers and developers, during this communication it is crucial to make sure be understood correctly, for example through open questions like "Did I explain myself well" that stimulates further discussion (Chechique, 2021). It is also advisable to work with visual examples and use diverse documentation formats such as user flows and video, particularly for complex interactions (Chechique, 2021). Finally, both sides may refrain to their own technical jargon. For designers this could be topics "like typography x-

height, complementary color, or typeface names" (Chechique, 2021). It is advisable for both sides to speak as simply as possible and clarify any unclarities owing to technical terminology quickly.

For improving the workflow Bermon (Bermon cited in Lindberg, 2019) recommends choosing a separate delivery methodology that is suited well to the relevant discipline and keep a dual-track approach (Lindberg, 2019). A suitable methodology for designers could be based on UCD whereas developers would feel more comfortable with agile working methods that use design sprints (Lindberg, 2019). Bermon (Bermon cited in Lindberg, 2019) describes the resulting tracking options as follows:

- **"The discovery backlog: *Designers work through requirements, reframe them as assumptions, and aim to validate them. There are a couple of benefits to not forcing designers into a sprint model: It allows them to ebb and flow within the context and complexity of the requirements they're working to validate, and it encourages support from the development team. The result is validated requirements that can then be filtered into a more traditional implementation backlog.***
- **The implementation backlog: *This is where user stories, acceptance criteria, and the correct level of design documentation lives. Since designers and developers have decided what should be implemented together, and each requirement has been validated for both customer fit and technical feasibility, less context is lost and less rework is likely" (Lindberg, 2019). Finally, designers are expected to be included beyond the actual design process and driving implementation of design initiatives in the organization, which requires design students to be eloquent in business language and managerial talk alike.***

Designers must also communicate with their clients and users. Some recent work suggests that this communication may include three aspects of looking at a design process (Lawson, 2005). The first refers to the actual process as carried out and may be called design practice, much of which described as design process and design handover is included in this aspect (Lawson & Dorst, 2009). Secondly, there may be a formal description of the design process in description, documentation, contracts, terms of engagement and so on that outlines the intention of the design communication (Lawson & Dorst, 2009). This formalization is of extreme importance in large and complex organizations that follow hybrid working models. Finally, Lawson & Dorst (2009) identify a third aspect of communication process that describes the process that those involved in the design work may wish to follow, called aspiration. Organizations ideally give leeway to teams to follow their aspirations without compromising the other aspects.

The key learning for design students could therefore be that communication will be much more complex than they expect because the three aspects described may be aligned or not aligned, which may be the source of potential confusion when communicating with other stakeholders such as clients (Lawson & Dorst, 2009).

Therefore, design education should give students the chance to develop their core design competence, their expertise in navigating complex situations along with the preparation to be visionary designers (Schaeffer & Palmgren, 2017). According to Dreyfus and Dreyfus, 2005 and Lawson and Dorst, 2009 cited in Schaeffer and Palmgren, 2017:

"This includes giving them the opportunity to learn how to be highly involved in the problem, respond to a situation intuitively, finding new ways of doing things, redefine issues and be radically innovative."

Four diverse prototyping exercises were applied in the study of Schaeffer & Palmgren (2017) in order to address the learning areas of active experimentation and concrete experience as depicted in figure 2:

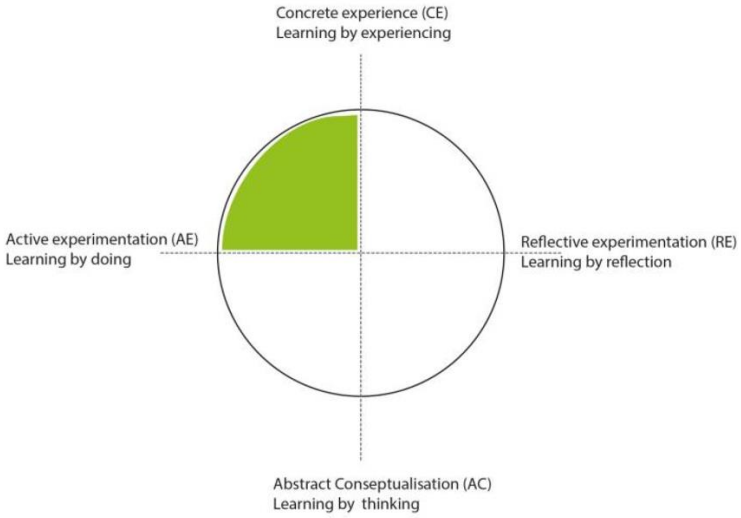

Figure 2: The Learning Cycle (adapted from Kolb and Fry, 1975 and Saloma, 2015 cited in Schaeffer and Palmgren, 2017)

The exercises allowed students to define the design problem and "were also designed to support collaborative exploration of a design scope, questioning it, and exploration of how interaction of materials and the body could influence the design process and final design" (Schaeffer and Palmgren, 2017).

The outcomes, however, were mixed and established the existence of two uniquely different attitudes in response to the challenge, namely "aversion" or withdrawal of students or "immersion". As one possible reason for aversion the authors described a potential mismatch between their skill level as novice designers and advanced expectations in terms of recognizing subtle sense of context, exploring new domains and new trajectories for design (Schaeffer and Palmgren, 2017).

Therefore, design students today require a formal basic training that equips them to capture the wider competencies related to design practice work as outlined including social, organizational and communication skills while at the same time enhancing their understanding and visionary approach to design for mastery.

Conclusion:

Prototyping in design is a very hands-on activity grounded in thorough understanding of design theory and practice. It is a key part of every design project with a low threshold for action and participation. As a result, prototyping transforms the design idea into a tangible artefact, thereby reducing uncertainty and deepening the contextual understanding, including through its experimental character and the iterative nature of prototyping a closer approximation of the design fit to user expectations and abilities. Design students are therefore challenged with dealing a much "messier" reality than models would suggest, the inherent bias towards action even if key assumptions are not yet validated and doing that all in an economical way and inclusive way. Using prototypes beyond the functional and aesthetical aspects requires superior communication skills, especially when promoting prototypes into larger organizational contexts and using prototypes to communicate with stakeholders outside of the design community. The author argues that this aspect of navigating complex scenarios and transporting the design vision inherent in the prototype to a diverse audience would be a worthwhile addition to design education. To address elements of design practice in prototyping, design curricula should ideally include practical application scenarios that represent or solve real-life design challenges and address them in a plan / act / reflect learning cycle with a focus on practical learning outcomes. Both can be achieved in a classroom and distance learning setting provided the participatory and iterative perspectives can be

addressed through work structure assignments and / or digital tools.

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