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A generative toolkit to help raise industrial design students' awareness of low metal recycling rates

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Abstract

Education for Sustainable Development requires raising individuals' awareness of problems relevant to the environment. We designed a Generative Toolkit that supports industrial design students carrying out a Speculative Design task and through this process initiates greater problem awareness of low metal recycling rates. In this paper we give insights into the Toolkit's theoretical derivation and the design process. Findings from testing suggest that there are several opportunities for improvement, such as considering further content-related competencies in the Toolkit's design.

Keywords: design education, circular economy, design tools, sustainable design, collaborative design

1. Introduction

The demand for metals is rising worldwide. In industrialized countries, this is particularly due to the expansion of modern, metal-intensive technologies (UNEP, 2013) such as a wide range of clean energy- and information and communication technologies (International Energy Agency, 2023; Zhang, Yan and You, 2023; Carrara *et al.*, 2023). Many of these technologies rely on the availability of metals that are of high economic importance, while at the same time their supply is subject to significant risks (European Commission, 2023). Recycling these so-called critical metals contributes to conservation and secures their supply. As a prominent R-strategy (Potting *et al.*, 2017), recycling is therefore considered an essential component of the Circular Economy Action Plan of the European Union (EU) (European Commission, 2020). Moreover, metal recycling can be more environmentally friendly compared to primary production (UNEP, 2013; Liedtke et al., 2014).

However, recycling rates of most metals are currently relatively low, not only in the EU but worldwide (UNEP, 2011). Reasons for this kind of metal dissipation (Ciacci *et al.*, 2015) at the product level are the increasing complexity and miniaturization of digital technological devices (Ayres, Mendez and Peiro, 2014). Industrial design locates itself at the early stage of product development processes. As many critical decisions surrounding the nature of a product are determined here, the discipline is potentially in a good position to influence its environmental impacts for the better (Lofthouse and Bhamra, 2000). This is also true in terms of a product's recycling potential (Graedel, 2011), as studies on the modular Fairphone 2 show (Reuter, Schaik and Ballester, 2018). In the context of Design for Sustainability (Ceschin and Gaziulusoy, 2016), the incorporation of environmental aspects into product development processes is summarized under the term ecodesign (Karlsson and Luttropp, 2006). It's goal is to minimize the consumption of natural resources and energy, including the resulting environmental impacts, while maximizing customer satisfaction (Ceschin and Gaziulusoy, 2016). The latter depends, e.g., on issues of ergonomics, aesthetics and safety (Luttropp and Lagerstedt, 2006). Ecodesign focuses the entire life cycle of a product (Ceschin and Gaziulusoy, 2016). Product disassembly and recycling are therefore essential elements of environmentally friendly design (Luttropp and Lagerstedt, 2006). However, in order for industrial designers to be able to commit themselves to improve the environmental performance of their products and to make use of the many possible tools and methods that already exist in the field of ecodesing (Rossi, Germani and Zamagni, 2016; Kattwinkel, Song and Bender, 2018), it is necessary to sensitize them to environmentally relevant problems and to raise their awareness accordingly. 'Promoting public awareness' (UN, 1992) is a key means of implementing Agenda 2021 and is considered an essential component of Education for Sustainable Development (Rieckmann, 2012). Education for Sustainable Product Design has therefore already established itself in research and teaching at some higher education institutions (Watkins *et al.*, 2021). To help raise awareness among industrial design students about the environmental problem of low metal recycling rates, we developed a Generative Toolkit and tested it with the target group as part of an educational format at the University of Wuppertal, Germany. Because we want it to be as effective as possible, we asked the target group what they consider to be the potentials in terms of content and design. In this paper, we provide insights into the theoretical background and the stepwise development process of the Generative Toolkit, resulting from the feedback obtained. In Chapter 1.1 we start with an overview of available ecodesign tools for sustainable product design. In Chapter 2, we describe the theoretical background of our Generative Toolkit and reflect on the methodological approach. In Chapter 3, we characterize the developed prototypes while summarizing findings from testing. We conclude this paper in Chapter 4 with a selection of key findings that can have a positive impact on the design of future Generative Toolkits to raise problem awareness even more effectively.

1.1. Background

To integrate sustainability aspects into product development processes, there are corresponding tools for industrial designers (Lofthouse and Bhamra, 2000). Especially for the environmental perspective of sustainability, many different so-called ecodesign tools are available to them (Rossi, Germani and Zamagni, 2016; Kattwinkel, Song and Bender, 2018). These range from very simple generic tools to complex and time-consuming methods (Bovea and Pérez-Belis, 2018). Tools are also used in educational contexts at higher education institutions. Below, we provide an overview on a brief selection of design tools that are relevant to our work and relate more or less directly to metal recycling.

Initially, we look at the work of Lofthouse (2006), who explicitly addresses the needs of industrial designers with her ecodesign tool 'Information/Inspiration'. It is a web-based design tool that brings together, e.g., information on existing tools, widespread strategies for ecodesign, and aspects of the End-of-Life phase of a product. The tool sees itself not only as a source of information, but also as a source of inspiration and thus provides insights into case studies. In her study and in further tests, the author identifies general requirements for the design of ecodesign tools, which she summarizes in a holistic framework for future versions focusing on industrial design. The requirements include the following elements: 'inspiration', 'information', 'guidance', 'visual' and 'nonscientific language'. In their paper, Whalen et al. (2018) present the serious game 'In the Loop' about critical materials and the concept of Circular Economy (CE). They address engineering students to gain a better understanding on the topic of material criticality and enable them to propose possible solutions in the context of CE. Luttropp and Lagerstedt (2006) present generic guidelines for integrating environmental aspects into product development with their 'Ten Golden Rules'. They offer a simple introduction to the field of ecodesign. To be really useful, the guidelines have to be adapted specifically for each product. The tool can be used, e.g., as a checklist during design activity. Guidelines nine and ten in particular deal with improved recycling by avoiding the use of alloys and selecting reversible joining techniques. Van Schaik and Reuter (2014) with their '10 Fundamental Rules & General Guidelines' aim very much at improved metal recycling by adjusted design. Their product-specific approach is based on physical and thermodynamic fundamentals of recycling systems. A compatibility matrix can be created for each product. Incompatibilities of metals in the different processing stages of the carrier metals can thus be identified (UNEP, 2013; Worrell and Reuter, 2014). In the context of environmental assessment, 'Footprints' have developed as lifecycle-wide, narrowly defined environmental metrics. These address single impact areas, such as the Material Footprint focusing on abiotic and biotic resources (Lettenmeier et al., 2012). They are considered easy to use and understand indicators for non-experts (Hauschild, Rosenbaum and Olsen, 2018). For the metal recycling perspective, there are the End-of-Life Recycling Input Rate (EoL-RIR) and End-of-Life Recycling Rate (EoL-RR) indicators. Both are used to monitor the status of CE in the EU. For example, the EoL-RR represents the proportion of a material in waste streams that is actually recycled. It characterizes the performance of collection and functional recycling of a metal (Peiro Talens *et al.*, 2018). In addition to individual ecodesign tools, comprehensive design guides are also offered in the educational context (Liedtke *et al.*, 2019; van Boeijen, Daalhuizen and Zijlstra, 2020; UBA, n.d.). So far, we can note that relevant design indications of ecodesign tools are pointed out by Lofthouse (2006). Raising awareness of students is concern of the work of Whalen et al. (2018). The thematic focus of metal recycling, on the other hand, is central in the tool of Van Schaik and Reuter (2014) and is also the subject of the CE monitoring indicators EoL-RIR and EoL-RR (Peiro Talens *et al.*, 2018). In the Generative Toolkit we developed, we merge the goal of raising awareness with the topic of metal recycling, addressing industrial designers. We frame it within the context of an educational format providing a theoretical input and promote creative exploration as part of a design task to let students discuss possible solutions for the problem of low metal recycling rates.

2. Materials and methods

In the following Chapter 2.1 we specify the concept of environmental awareness, which is essential in the context of Education for Sustainable Development. Problem awareness is also taken up in social psychological models of behavioral explanation (Schahn and Matthies, 2008). In Chapter 2.2 we focus on the background of Generative Toolkits. We then turn to the Speculative Design (SD) approach as our chosen design method in Chapter 2.3. We finally come to our methodological approach in Chapter 2.4.

2.1. Environmental awareness

Environmental awareness can be precisely divided into the three components (i) 'environmental knowledge', (ii) 'environmental attitude', and (iii) 'environmental behavior' (De Haan and Kuckartz, 1996). In the context of Education for Sustainable Development, promoting appropriate competencies is added to the creation of environmental awareness (Rieckmann, 2012), to enable individuals to behave in an environmentally appropriate way. Knowledge about or perception of problems is also the first step towards action in Schwartz and Howard's (1981) model of normative decision-making. In its first stage, the awareness of possibilities for action and awareness of one's own abilities are additionally added, so that a 'feeling of moral obligation' (Schahn and Matthies, 2008) is generated. Rieckmann (2012) presents key competencies for sustainable development. These include, e.g. (i) 'systemic thinking and dealing with complexity', (ii) 'anticipatory thinking', (iii) 'critical thinking' and (iv) 'empathy and change of perspective' and (v) 'planning and realization of innovative projects'. Other generic key competencies from the literature are summarized by Wiek et al. (2011). For industrial designers, these key competencies are an integral part of their professional profile (Archer, 1979; Schön, 1983; Cross, 2006) and are embedded in higher education institutions curricula (Watkins *et al.*, 2021). More relevant for them and thus for our work are therefore the content-related competencies from the field of learning competencies (Solzbacher, 2006) to raise problem awareness for low metal recycling rates among the target group and to indicate hints on possible courses of action that may lead to environmentally friendly behaviour.

2.2. Generative Toolkits

Originally, Generative Toolkits with their ambiguous nature are aimed at non-designers. They are supported in collaborative design processes to generate artifacts and thus express their thoughts, feelings and ideas (Sanders and Stappers, 2008; Brandt, Binder and Sanders, 2013). However, Generative Toolkits can be used by all people to 'make artifacts about or for the future' (Sanders and Stappers, 2014). The process of making is usually guided and occurs individually or in small groups. The verbal addition 'generative' is aligned with the generative phase of a generic design process and emphasizes the forward-looking, exploratory, and constructive concern of these Toolkits (Sanders and Stappers, 2014). They consist of several components that can be arranged and combined in various ways. There is usually

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a background on which the people using them can work. The design of a Toolkit is fundamentally context dependent (Sanders, 2000; Sanders and Stappers, 2014). In what follows, we refer to Generative Toolkits as Toolkits for the benefit of simplicity.

2.3. Speculative design

The main differences between SD and classical engineering design are illustrated by Dunne and Raby (2013) in their A/B Manifesto. Basically, the approach is less about solving problems, but about finding and pointing them out. Design is not seen as a solution, but as a medium to 'provoke action, spark debate, raise awareness, offer new perspectives, and inspire' (Dunne and Raby, 2013). The conceptual boundaries with relatively similar approaches such as design fiction (Bleecker, 2009) are not clear-cut and possible approaches are considered context-dependent (Auger, 2013). In literature, project-specific design processes of SD are described in e.g. Dong et al. (2020) and Johannessen et al. (2019). SD projects share certain similarities that we consider as key elements. Central to the design is including an object. As a component of social practices, it is usually related to the subjects using it. The two key elements are framed by a scenario based on a 'what-if' question. Essential are the scientific foundation of the scenario and a real-world reference. To meet the overall goal of the approach of raising awareness of a particular target group, SD is related to typical qualities, described e.g. as critical, inspiring, provocative and ambiguous (Auger, 2013; Dunne and Raby, 2013, 2021).

2.4. Methodological approach

Co-creation (Sanders and Stappers, 2008) is the basis for designing our Toolkit. Collaboration takes place via three stages to gradually advance to the latest design. The starting point of our design process is the SD approach. Our basic idea is that by making and engaging in the process of SD, students become aware about the problem of low recycling rates. We have derived a corresponding SD process, which is particularly well illustrated in the first Toolkit (Figure 1). We tested this first version in user studies (Moran, 2019) with eight non-designers to get a basic feeling for SD and to practice guiding Toolkits overall. We designed our second Toolkit based on the collected insights from the initial development process and testing. This is the first time we have addressed our actual target group and thematized the finiteness (Giljum and Hinterberger, 2014) and availability (van Oers and Guinée, 2016) of metals. We tested it with five industrial design students at Burg Giebichenstein, University of Art and Design Halle, as part of a one-week workshop on the overarching theme of metal dissipation. We collected statements on the effectiveness and potentials from the perspective of the target group using an anonymous feedback survey. On this evidence, we finally designed our third Toolkit. We tested it as part of an educational format at the University of Wuppertal with thirteen fourth-semester industrial designers. Once again, we used an anonymous feedback survey and conducted occasional semi-structured exploratory interviews. In Table 1 we summarize our approach and the characteristics of the Toolkits.

Table 1. Overview of the three Toolkits' characteristics (No. 1-3)

No.	Target group	Awareness for…	Competencies promoted	Survey technique
1	Non-designers	…possible effects of current technological development trends	Rather higher-level key competencies of sustainability, especially anticipatory- and critical thinking	Semistructured exploratory interviews
2	Industrial designers (Burg Giebichenstein, University of Art and Design)	… possible effects of metal depletion on everyday human life	More content-related competencies, in particular: Finiteness and availability in connection with fields of metal application	Anonymous feedback survey
3	Industrial designers (University of Wuppertal)	… low recycling rates and high import dependency of metals (EU)	More content-related competencies, in particular: Recycling rates, import dependencies, EoL-RR indicator	Semistructured exploratory interviews and anonymous feedback survey

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3. Findings

In the following, we describe the findings from testing each of the three Toolkits. We start with the first version, which is still aimed at non-designers in a very general and thematically overarching way. Over the development steps, our thematic orientation becomes more pointed and we finally address our actual target group. We modify the design of the Toolkits according to our collected feedback. We conclude each of the following subchapters with an overview of potentials in terms of design and content from the target group's perspective.

3.1. First Toolkit

With the first Toolkit (Figure 1), we lay the foundation for the development of the other two following. We are mainly guided by the characteristics of the SD approach (Chapter 2.3). The Toolkit is intended to encourage and support users to speculate about futures. Primarily, they should gain an awareness of possible impacts of current technological development trends and learn to take a critical position towards them. The Toolkit consists of three main components, which can be extended with some sub-components. Basically, it manifests the SD process we derived. In component **(a)**, users create their 'what-if' question. They can choose between different megatrends (Zukunftsinstitut GmbH, 2023), which are either utopian or dystopian. In component **(b)**, users choose a time horizon to which their scenario refers. Additionally, they have possible qualities at their choice to accentuate their scenario accordingly. Finally, in component **(c)**, users decide on a form of materialization for their scenario.

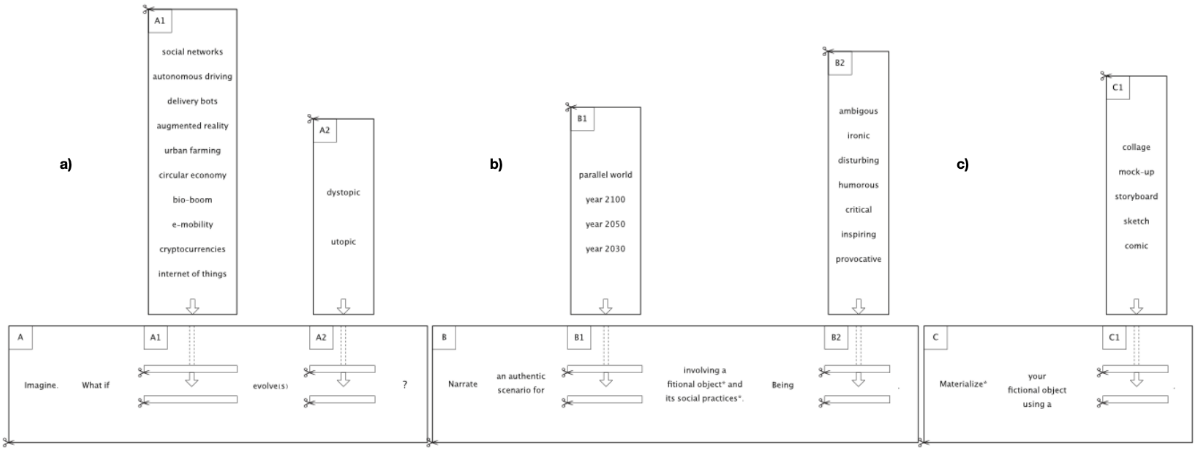

Figure 1. The first Toolkit consists of three components; It corresponds to our derived SD process and combines several SD key elements; Own illustration

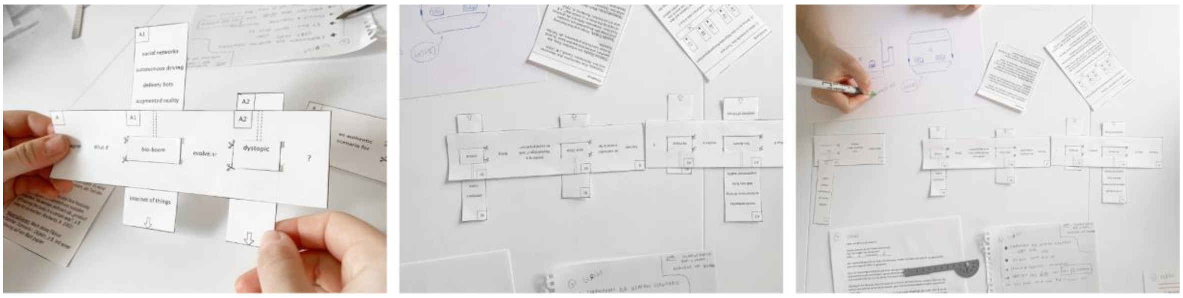

Figure 2. In action: The first Toolkit and also the other two can be printed and cut out

The user study (Figure 2) reveals that the Toolkit is basically convenient to work with. The sliding mechanism is easy to understand and the predefined parameters on the sub-components are seen as helpful. These give the target group a design framework guiding them through the process. At the same time, it is reported that adjusting the Toolkit with the available parameters is done rather randomly. In some cases, reconfiguration of the Toolkit even occurs during the materialization step. The target group

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does not find it so easy to deal with the predefined qualities in component **(b)**. These are even perceived as disruptive to the workflow.

3.2. Second Toolkit

The Second Toolkit addresses our actual target group for the first time. Before students start working with it, they get a short theoretical input. The Toolkit itself leads on to the SD task. Three components are the basis of the Toolkit that are reflected in Figure 3. Students are provided with **(a)** metal cards depicting QR codes. These pass on to serious references where students can obtain information on the uses of the depicted metals. Once they have chosen a metal, they can begin the SD task, guided by an SD process **(c)**. The task and further information about the procedure can be found on the manual **(b)**.

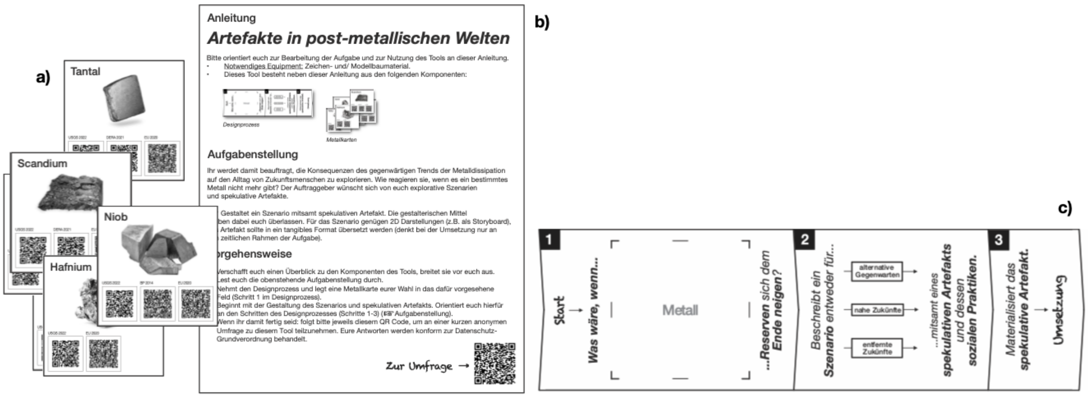

Figure 3. The second Toolkit consists of three components; Own illustration

The anonymous feedback survey indicates that the target group's awareness regarding the finiteness and availability of metals was strongly stimulated on average by the theoretical input and by using the Toolkit (level 4 on a scale of 1-5). The students basically liked designing future scenarios. This enabled them to actively work out complex correlations and to open up new fields of action. At the same time, the students criticized that the scope of the task was too large. They therefore found it difficult to get started with the task and would have liked a more concrete conceptual framing, e.g. in the form of a common overarching storyline, to which they could have subordinated their respective concepts. In fact, the students got together during the task and developed a common storyline. Three outcomes of the SD task are reflected in Figure 4.

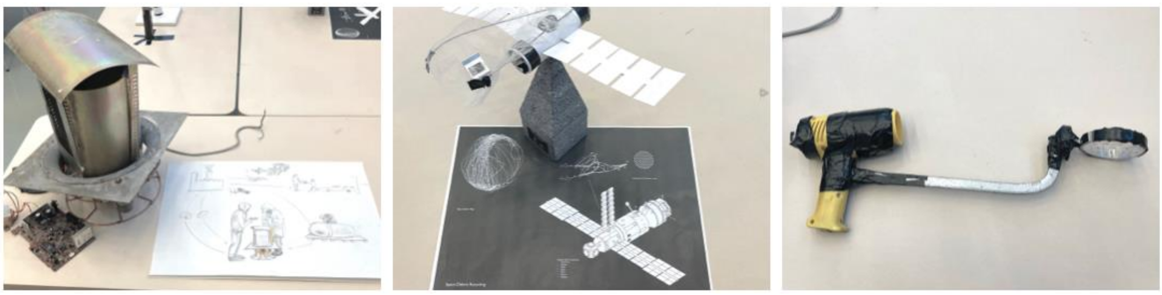

Figure 4. Three speculative artifacts created under the guidance of the Toolkit; Student's outcomes are anonymized (written permission was obtained to use their concepts)

3.3. Third Toolkit

The third Toolkit is also aimed at industrial designers and thus at our final target group. Once again, the students receive a theoretical input. This time it is about the final topic of low recycling rates in combination with high import dependencies of metals from EU perspective (Chapter 1). Students are also introduced to the EoL-RR as an indicator. The SD assignment is adapted to a re-design of a smartphone **(a)**. For this purpose, they are provided with a corresponding material inventory **(c)**. The aim is to design a speculative artifact based on all metals of the material inventory with >25% EoL-RR

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and thus to think differently and critically about communication. Other components of the Toolkit also include a workspace **(d)** on which students are supposed to record their concepts as drawings. There are charts on metal-specific recycling rates and import dependencies **(b)**. The four components of the Toolkit are reflected in Figure 5.

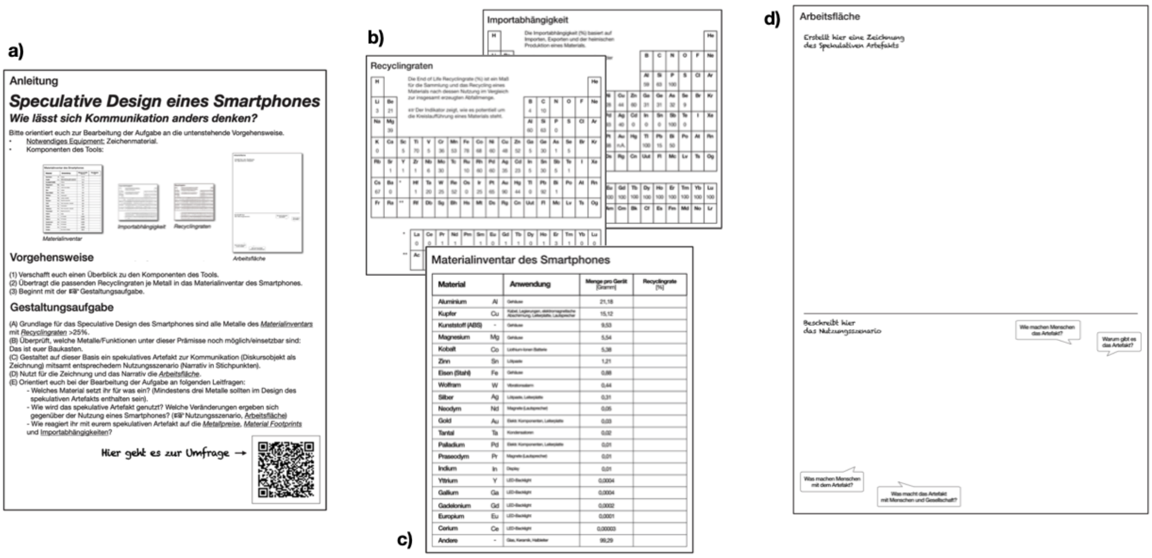

Figure 5. The third Toolkit consists of four components; Own illustration

The anonymous feedback survey shows that the target group's awareness of the problem of low recycling rates of metals was strongly stimulated on average by the theoretical input and the subsequent use of the Toolkit. 11 out of 13 students positioned themselves at level 4 on a scale of 1-5. Most of them were not aware that relatively few metals are recycled in the EU. Partly it was assumed that recycling of metals would work without any problems. The link to the EU's high import dependency on metals was noted as a positive. This again emphasized the importance of metal recycling. Students most liked the opportunity to redesign a concrete product and be able to work creatively without external constraints when using the Toolkit. Also seen as positive was the design based on a limited selection of metals. Less well liked by the students was the initial struggle with the charts required to update the included smartphone material inventory according to the upper limit of 25% EoL-RR. In addition, students commented that the task was a bit too abstract and far from reality.

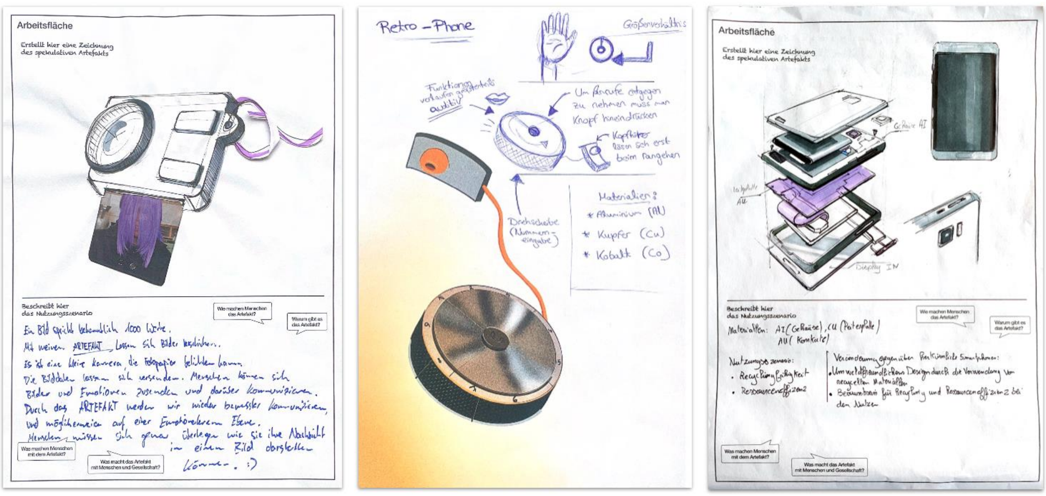

Figure 6. Three selected concepts from the SD task; Own compilation of the student's outcomes (anonymized; written permission was obtained to use their concepts)

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4. Discussion and conclusion

Our work is aimed at industrial designers whose special position in the product development process can positively influence the environmental performance and thus potentially the recycling of metals contained in products of modern, metal-intensive technologies. We have developed a Toolkit that supports carrying out a SD task and through this process initiates an increase in problem awareness of low metal recycling rates among the target group. In this way, we want to create the intellectual conditions for students to promote improved metal recycling in later projects with further content-related competencies, some of which already anchored within existing ecodesign tools. In this paper, we mainly describe the theoretical background of the Toolkit as well as the collaborative design process that moves in three steps toward thematic targeting and the final target audience. What is new about our approach in the context of Education for Sustainable Product Design is the combination of the concept of environmental awareness from social psychology, including learning competencies, with practical exploration by the students as part of a SD task guided by a Toolkit. Subsequently, we reflect on some findings from development and testing. We thereby hope to inspire future work in this thematic context and beyond.

From the testing of our first Toolkit, we can derive that it can be useful, especially when speculating about futures, to provide the target group with a design framework as orientation. In this way, 'wild speculations' (Dong *et al.*, 2020) can be avoided and it can be ensured that the target group is not overwhelmed with the task and with the multitude of infinite creative possibilities. The given qualities of SD are not profitable for the design. This is easy to understand, since the task is about increasing individual awareness and thus about one's own preferences, which only emerge in the later design process. The testing of the second Toolkit particularly reinforces the implementation of an even more concrete framing of the scope of action within the SD task. The students introduce this independently by coming up with a common storyline. Working together on a unified storyline strengthens the group's interaction and has a beneficial effect on the final presentation of results. Since the students had more time available during the workshop, they decided to use prototyping as their design means. Appropriate materials were available to them on university campus. We can also draw from the testing that the target group enjoyed speculating about possible futures in combination with present metal information. In association with the promotion of content-related competencies on finiteness and availability of metals, the awareness of the target group was strongly increased. Testing the third Toolkit, we can state that the target group's awareness for the problem of low recycling rates was strongly stimulated as well. Even though this statement is not representative due to the small group size, just as with our previous second version. On this basis, however, we can better classify the statements made by the target group about potentials. In this respect, e.g., we can note that the tabular information presentation of recycling rates and import dependencies does not yet correspond to the preferences of the target group. This is in line with the requirements for ecodesign tools identified by Lofthouse (2006). With the commented distance from reality of the task, students target the aspect of environmental behavior that some authors include in the concept of environmental awareness (De Haan and Kuckartz, 1996). With the EoL-RR indicator, students apparently do not yet feel competent enough to advocate for improved metal recycling in realistic longer-term projects. However, we refer at this point to the many ecodesign tools for the actual product development process that are available to students after raising their awareness. Therefore, an increased focus on realistic possibilities for action, as implemented in Schwartz and Howard's (1981) norm activation model, is beyond the scope of our work. At the same time, from our point of view, this perspective, as well as the further steps of the norm activation model, could prospectively be addressed, e.g., by market- and society-relevant aspects (Liedtke *et al.*, 2019) in future Toolkits aimed at industrial designers.

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