Learning Design for Children and Youth in Makerspaces: Methodical-Didactical Variations of Maker Education Activities Concerning Learner's Interest, Learning with Others and Task Description

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ABSTRACT
For some years now, "maker education" has been conquering the world, and with extensive literature describing projects and activities as well as their characteristics and effects. Many authors have described principles of maker education such as working on a product and do-it-yourself activities. However, the literature on how to develop and design a maker activity with children is still limited. This would be of interest to and inform the systematic training of teachers and maker educators. In this paper we propose an overview of the methodological-didactical variations in maker education base on the systematic analysis of the original principles of adults learning in makerspaces to extrapolate the principles for working with children in maker education. Therefore, this paper offers a collection of methodological-didactical variations concerning three aspects, namely (a) the inclusion of the learner's own interests, (b) learning from and with others, and (c) the kinds of task available at hand. In this way it is intended to offer practitioners support for the design and development of their own maker education programs.

Keywords: *maker education, makerspace, didactics, learning design*

1. INTRODUCTION

Maker education is a special application of digital technologies in schools today. Maker education is understood to be a learning or teaching setting in which characteristics of "making" and the "maker movement" are implemented. "Making" emphasizes the doing of things by oneself using manual and digital creative designs. It typically involves digital technologies such as 3D printers, computers, and cutting plotters.

In this article, we first describe the principles of maker education. Then we focus on the support needed for designing maker education for children and youth in formal as well informal contexts. Building upon the need for clearer guidelines for the design of maker education, we will analyze the work and learning of adults in makerspace to offer an overview of the methodological-didactical variations in maker education. Based on this overview, we will present a collection of activities and examples revolving around three identified characteristics for children learning in makerspaces: (a) consideration of individual interests, (b) implementing learning from and with others, and (c) variants of the task description.

2. PRINCIPLES AND BACKGROUND OF MAKER EDUCATION

Maker education is based on the idea of the creative, do-it-yourself activity in a workshop space with digital tools available for children and youth to use. Some general characteristics of maker education are as follows [1] Maker education, in comparison with traditional learning and teaching in schools involves children working on making/creating products, i.e. real-aim and digital products, objects, machines, apps, games or videos. Children learn and work in an open workshop structure, i.e. resources and (digital) tools are freely available and shared. The development of many maker projects involves interdisciplinary and transdisciplinary work to redefine the traditional idea of learning "school subjects" in siloes. When implementing maker projects, the focus on a product is important, but so is the process work on the product and the possibility of failure. We perceive failure as an important aspect and a possibility to expand one's own experience and knowledge. In maker education, adults act less of authoritarian teachers and more as co-designers and facilitators of children's learning. In many projects - this might apply more to Europe than to the USA – the maker activities tend to address sustainability issues or social participation, e.g. repair cafés in schools [2].

Publications on maker education make references to Seymour Papert and his "Theory of Constructionism" as the key figure in propagating maker education. This theory describes, less in a theoretical than in a practical sense, the construction or "digital do-it-yourself" as essential for learning [3] Different reforms in pedagogical approaches have emphasized the importance of objects for learning and of active designing and constructing, for example, Maria Montessori with her (albeit prefabricated) learning objects or Celestin Freinet with the school newspaper, which is printed by hand by his students. For the openness of the approach, the interdisciplinarity and the choice in the design of the products and the (learning) activities, students can achieve different learning goals and develop competencies from opportunites offered through maker education. Maker education is linked to the expectation that it is possible to develop personal and social skills such as self-organization, problem-solving, teamwork, project management, responsibility or stamina [4]. Making is also used to arouse interest in computer science issues among children, especially girls [5] Others use maker education to promote media literacy, in which children learn how to use and design digital tools The Europe-wide DOIT initiative, for example, fostered early social innovation capacities as well as entrepreneurial education for children and youths [6].

There exists many manuals and prescribed examples for successful maker education activities. Interestingly enough, and this is a particular challenge for the training of future maker education trainers (maker educators), very few are related to supporting teachers and maker educators to design and develop their own maker education programs.

Exemplarily, we refer to Martinez and Stager (2013), who offered four possibilities for using materials for making in educational settings: "1. Specific concept. Use the materials to teach a specific concept, such as gears, friction, or multiplication of fractions. 2. Thematic project. Visit a local factory, amusement park, airport, construction site, etc. and construct a model of it. Design a set for our medieval carnival. 3. Curricular theme. Identify a problem in Sub-Saharan Africa and build a machine to solve this problem. 4. Freestyle. The materials become part of your toolbox and may be used when you see it. This choice of media or medium requires student to develop technological fluency" (p. 65).

We see such concrete descriptions of different maker education design possibilities as very helpful for maker educators. The next section scopes the literature on existing forms of maker education in relation to the kinds of learning they aim to promote in order to identify the gaps in maker education design.

3. BACKGROUND AND RESEARCH DESIGN

The original model of maker education involves adults working on maker projects and (informal) learning in makerspaces. From a normative point of view, maker education aims to educate future makers to be creative and responsible designers of a potentially better world. Makerspaces also provide a model with regard to the method of engaging children to learn: Methodologically and didactically, children should also learn in a makerspace as adults do. However, children are not necessarily well prepared to develop their own creative and independent projects, seek support or work together with others.

In the "Maker Manifesto" there are several statements that specifically refer to learning [7]. According to this, the following aspects are particularly important for the maker movement in relation to learning:

- Self-organized learning - Determination of own learning goals and methods, also learning with the help of instructions and tutorials, especially from the Internet,
- Learning from peers - learning in cooperation and exchange with other makers
- Active sharing of learning experiences and projects with others, also on the Internet or on maker faires,
- Interest-driven work, also in creative, i.e. novel solutions and products and/or artistic implementations.
- The willingness and attitude to always want to continue learning.

We analyzed the characteristics of adult learning in makerspaces and derived from this how maker education has to be designed if it is to prepare children systematically for work and learning in makerspaces (see Table 1).

Table 1. Characteristics of makerspaces for adults and makerspaces for children within maker education (cf. Schön & Ebner, 2020).

	Makerspace for adults	**Makerspace for children in maker education**
Characteristic of makerspace	The makerspace is an open workspace for adults with informal learning opportunities and some formal offers	The makerspace is an educational offer, integrated into formal (school) and informal education (youth work).
Purpose of the Makerspace	Supports users of the Makerspace Offers users systematic training in the processes of using various tools	Fosters personal and social skills of children as makers, Teaches the use of tools and methods Considers and promotes interests (STEAM)
Tools	Involves various tools such as 3D printers, laser cutters, digital sewing and embroidery machines, woodworking	Involves mainly simple tools, computers, educational tools and special kits
Characteristics of learning	Learning is based … - on voluntariness and interest - cooperation and peers - predominantly self-organized and self-directed - on diverse projects that can be small, e.g. for repairs and can extend to new industrial development - on usage of Internet instructions and community - on informal learning as well as on trial and error	Learning design should … - take into account the interests of children and self-organisation of learning - promote and foster learning with and from others - work with a variety of challenges from small-scale to goals for a better world - foster creative developments including the possibility of failure as well as trial and error

We use this comparison in Table 1 to elaborate on how we can design maker education for children and also for the further education of maker teachers and educators. Building upon these experiences, we see a need for a systematic collection of methodological-didactical variants to address the following three questions:

- How can interests of children be taken into account in maker education?
- How can we to promote and foster learning with and from others in maker education?
- How can we implement a variety of tasks from those that are instruction-based to those that promote innovations?

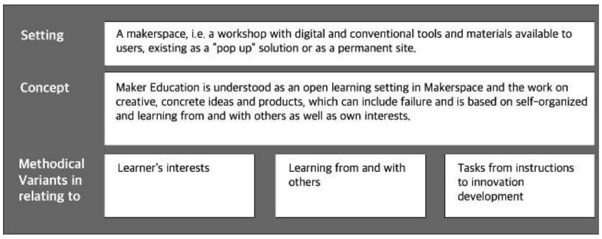
We know that these questions are also of a fundamental pedagogical-didactic nature. And there are basically many learning approaches and concepts that take these demands into account. This includes, for example, the project method by Kilpatrick to contemporary project-based learning [8]. However, references to such approaches are often not sufficient, especially for people who do not have an explicit pedagogical background or expertise, to develop a concrete maker education activity. Additionally, although project-based learning includes aspects of peer learning it does not present explicitly diverse possibilities to learn with others. Our participants wanted collections of different approaches and strategies that addressed precisely these learning challenges for maker education. Of course, there are several handbooks on maker education with examples of activities, but they follow different structures in their presentation, e.g. very often concerning tools and technologies or in terms of time and number of children. Early examples of such collections are published by Martinez and Stager (2013), Maker Media (2013), and the New York Hall of Science (2013).

Therefore, we will structure and describe the different possibilities and variants that we have identified from maker education projects based on our experiences in order to be able to answer such inquiries in the future. Our research design follows the analysis of project descriptions and presentations with real life observations of different maker education settings we have been involved in. These were mainly, but not only the “Maker Days for Kids” series, an open, temporarily makerspace for children from 10 to 14 years, developed in 2015 and re-organized and adapted three times since then in Germany and Austria. Within the “Maker Days for Kids” event, children can make anything by following their own interests and at their own pace, in an open makerspace setting with several working spaces, tools and (peer) tutors, organized in diverse variants and focuses. Additionally, we used project descriptions from our handbook on maker education, experiences in project we were involved such as the DOIT initiative or other projects such as “Jugend hackt” [9] and WILMA [10] We discussed a draft of our results with three maker education experts in a focus group discussion in December 2019 and revised it to the version presented here.

4. VARIANTS OF ACTIVITIES IN MAKER EDUCATION

Against the background of the understanding of maker education as “learning in a makerspace”, we have become acquainted with several implementations of “maker education” from a methodological-didactic perspective in different settings, inside and outside the school and in an international context. From our perspective, these methodological-didactical variants for children learning in makerspaces can be overviewed and traced back to three aspects, namely (a) the inclusion of one's own interests, (b) learning from and with others, and (c) the task at hand (see Figure 1).

Figure. 1: Overview of background and focus of our analysis on methodological-didactical variants in maker education



5. ACTIVITIES REGARDING THE LEARNERS' INTERESTS

When adults create a product in makerspaces, they do so out of their own interest rather than due t extrinsic motivations such as income or recognition. People are interested in makerspace; it moves them or appeals to them. But, in school settings, the curriculum and textbooks provide a framework for dealing with learning topics. In schools there are comparatively few options for choosing one's own focus or sequences in which a topic is dealt with. In makerspaces, therefore, children and adolescents should be given the opportunity to deal with things that are close to their hearts, especially if they strive to learn “as in a makerspace”.

Basically, it would be advantageous for children and youth to learn voluntarily in makerspace settings. This does not mean that the work in the makerspace setting has to be free of rules, teachers and students can - as is usual in a makerspace - also jointly determine agreements on the process, participation and other rules (“code of conduct”). In addition, there is a wide range of activities in makerspaces that can support learner’s learning interests.

5.1 “Free work” in makerspace

Using the makerspaces for the “free work” of students, which builds upon their own interests and needs, is offered at only a few schools so far. This does not mean that there are no rules here, e.g. for the use of tools and materials, such as introductions to protective measures as a prerequisite for some tools or restrictions in using materials (amount of filament per 3D print). An example for free work is: “The school’s makerspace is open for students every Tuesday from 14.00 to 16.30. You can use the room for your school projects or private ideas in consultation with the supervising person.” This activity allows children and youth to pursue their own interests and discover things in their own way. However, the approach also carries the danger, especially for beginners, that they do not know what they can do and feel overwhelmed. This approach has the potential for very special, creative processes, results and learning experiences.

5.2 Selection of different introductory projects and workshops

When students use a makerspace for the first time, they do not yet know its possibilities and tools. Here it makes sense to offer several projects and activities for students to choose from. An example for this is in the “Maker Days for Kids”, an open digital workshop, where participants can freely choose between several introductory, parallel workshops or work areas.With such an activity, students gain access to a makerspace through introductory workshops and activities that can further interest them to participate Students can also get a taste for other workshops and may find them interesting in line with their own interests.

5.3 Choice of topics or problems

Which topic do we want to cover in our makerspace? Is there a problem for which we want to find solutions in our makerspace? At the beginning of the co-design workshops of the European initiative “DOIT”, children and youth commit themselves to concrete topics or problems in a larger topic area, for example, the sustainability goals of the United Nations (cf. UNICEF, 2017). This approach is suitable when interdisciplinary skills such as teamwork or project management are addressed, or when specific methods should be practiced, e.g. programming an interactive story using the online programming environment - Scratch. In the DOIT project, children determine in advance in a co-design workshop on topicd they would like to work on, e.g. “Motivating people in the Tennengau to cycle” under the topic “climate action” (cf. DOIT, 2020). Within such an activity, students work on topics that are important to them. They use methods and tools or procedures given to them by the teacher, such as designing a 3D model, design thinking, programming an app.

5.4 Choice of Methods and Tools

For specific topics in the curriculum, the work in a makerspace can be pre-defined in terms of content. For example, teachers may want students to work on building styles over time, the periodic table, or Goethe's work. Besides the discussion of content, however, a makerspace opens up different procedures and tool uses. In the case of architectural styles, for example, one group could build prototypes out of cardboard, convert other architectural styles into 3D modelling, and another group could create an “interactive poster” (e.g. with a Makey kit) about building styles. In this learning activity, students get the assignment to work intensively on a common topic, but have freedom in the choice of tools and methods used. Students are introduced to specific, but different tools and methods. So it is possible that students develop unique products and solutions on the same topics.

5.5 Choice of Pace and Learning Methods

There are only a few (homework) assignments and project work where students can independently deal with learning content in schools. Such tasks can be realized and supported with the help of makerspaces in schools. Within a learning activity with being the choice of pace and learning method, students can work at their own pace, as well as draw from tutorials when needed. This could mean that students get the assignment to deal with a new topic by a certain point in time and to implement the solution (also) in a makerspace. For this to be possible, students will need to get access to tools and materials and instructions to help them create a product on their own in a makerspace. Within this learning activity, students must be clear about the task and conditions. They also need self-organized learning competencies, e.g. they need to have experience in determining their learning pace and methods or receive specific support in this respect.

5.6 Choice of Own Role in Project Work

In collaborative learning settings such as group work, individual students design their roles or their contribution to a joint project work in consultation with their partner(s). Group work enables students to choose the focus of their work - in cooperation with other group members. Within this learning activity, students can work in groups to explore their preferred topics or approaches. There is a danger here in that students who often work in such group work, take on the same tasks again and again through routine therefore limiting themselves and their potential learning.

5.7 Rarely: Instruction

Finally, teachers can also design learning experiences in a makerspace in such a way that there are no options for choice or co-determination by the students. This is then - as in school lessons according to the curriculum - sometimes necessary so that all students have the chance to deal with a topic, tool or method to understand and use it in principle. However, such a phase can only take up a minor part of the work in a makerspace. If a learning offer exists only through pre-defined learning settings without the possibility of choice, we cannot assign it to maker education. We mainly use this in maker education when, for example, alternative methods and tools are introduced and protective measures are necessary. For this, teachers give tasks, e.g. instructions, and methods and arrange the work without freedom of choice or focus. Within this learning activity, all students have dealt with the same topics and methods and thus theoretically have the same opportunity to learn them. In such a setting, students can get to know topics or methods that may not have interested them, but which could arouse their interest.

6. ACTIVITIES REGARDING LEARNING WITH OTHERS

Learning with and from others is a further perspective on different makerspace activity formats. For adults in makerspaces, it is normal that they learn with and from each other. In working with children and youth, these formats are often more unusual and require a new understanding of the role of the adults involved. This perspective shows that learning has a social agenda designed for the mutual support and the contribution from one's own strengths and interests.

6.1 Adults as Co-Designers

In makerspaces, there are usually users who have more experience with some methods. Unlike in the classroom and traditional teaching, teachers are much less likely to be experts in everything, even though they may be a step “ahead” of the beginners. In a makerspace, teachers are less in demand as experts than as process facilitators who intervene in critical situations, but otherwise remain in the background. Entrepreneurs, makers, parents, etc. can take part in makerspace activities to accompany students during the implementation. They are part of the development process, e.g. by giving feedback on the current implementation, also by providing an expert’s perspective. Within this learning activity, adults - especially if they are used to traditional teaching or as parents - must be prepared well for their role, i.e. they should see themselves as facilitators of learning. Some important, but simple basic rules are: 1. never intervene without being asked and touch projects or laptops and 2. students' ideas should be privileged and not their own.

6.2 Exchange of Experiences and Results in The Process

Where are the others? What have they achieved so far? How do they solve a problem? - Answers to such questions, which enable learning from the experiences of others, can be integrated in maker education. This can be an intermediate presentation of previous work and learning achievements, presentation of the biggest failures and challenges and consequences or research on the Internet on existing solutions and procedures. A feedback cube with helpful questions such as "What do you like?" or "What would you do different?" can be a support for feedback rounds for younger children. According to our experiences, the facilitators need to encourage and share that ideas "of others" can and should be used, and if, we should attribute them. To our experiences, children appreciate if they can get feedback from their peers or an external expert and not as usual, their teacher.

6.3 Support of Peer Learning in Makerspace

Mutual learning from peers, typically from classmates in school settings, can be implemented in a makerspace using various methods. As an example, more experienced students can support the introduction of methods and tools. Students can also be (co-)designers of manuals or workshops. This might serve as a snowball activity for learning: A small group is introduced to a new tool or technique and then independently guides others. Within the "Maker Days for Kids", peer tutors take part in the tutor training and serve as tutors as participants' older colleagues. This learning activity refers as well to learning by teaching and allows advanced students to further develop their learning.

6.4 Learning through Collaborative Work and Group Work

By working on joint, i.e. collaboratively created, works and group work, students can learn casually from each other. An example is a small group which works together to develop a prototype of a friendly garbage can that will thank the users. Another example is small groups of students who create interactive atomic models. Within this learning activity, the members of a team should be happy to work together, but this does not mean that teachers cannot have a say in the composition of the teams and groups. We recommend, if the children know each other and are new to you get the teacher to group the children (if accessible). The processes in the group have an obvious effect on learning, and the tutors should observe and monitor them including changing groups around if needed to support the best learning outcomes possible.

6.5 Development of Learning Resources by The Students

Hatch's Maker Manifesto (2013) emphasizes that makers also share their knowledge, learning and results with others. This suggests that students should also be involved in developing learning resources for making. An example is that we ask students to improve and publish an existing instruction for building a simple LED pillar candle or that students design and create video tutorials for using the tools in a makerspace. Within maker education, learning resources should also be made available online under open license. So, within this learning design, in terms of content, the use and significance of open licenses can also be discussed here.

6.6 Development of Learning Opportunities for Others by The Children

Finally, learning opportunities in makerspaces can also be offered to children to design the learning experiences for others: These could be, for example, workshop offers for (younger) classmates, but also for interested adults. At the "Maker Days for Kids" in Leipzig (2019), digital participants acted as tutors for the last day and we invited parents and other adults to participate in the open, workshop [11]. In another project called "I'll show it to you" students showed peers and their parents how to create learning videos on the tablet [12]. Within this learning activity, when parents and teachers become the participants, children can be inspired to be the teachers allowing adults to gain additional insights and perspectives regarding children. Some adults may need (if they see themselves as experts) explicit reminders not to dominate in the workshop.

7. VARIANTS OF TASK DESCRIPTIONS

A different, albeit related, perspective on methodological-didactic formats in makerspaces with students can arise from the tasks. Here, too, there is a broad spectrum of tasks from those that have few or no formal learning objectives and rules to those that are instruction-based with little or no leeway in a (correct) implementation.

7.1 Making without Specific Task Instructions

There are rarely makerspaces where students are not given any tasks or objectives. However, phrases such as, "Just try it out" or "Do what you want" can give students the freedom to discover or pursue their own interests. Examples of implementation are, for example, the "Maker Days for Kids" makerspace where participants are free to choose how they spend their day and take up whichever tasks they wish. Another simple but guided task assignment is: "This is an Ozobot, we can program it with the help of colors. Do you want to try it out?" or "Here you have a lot of cardboard and hot glue - you can build whatever you want with it!" Such learning activity allows for free, playful learning exploration and design. As anything is possible - even doing nothing could be a result - there can but does not have to be concrete projects and results.

7.2 Problem-Based Task

We outline a problem that offers a variety of approaches and solutions. For example, the initiatives “Jugend hackt” and “WILMA initially pose problems at the beginning of the group work-based workshops that deal with social problem solutions, e.g. climate change or migration. Such a task offers various creative solutions. Examples are: “There is always a lot of rubbish in the schoolyard. Design a product that will help to solve this problem.”, or “We want the citizens of our city to become fitter. Which products can help?” or “We would like to have a lot of income at our sales stand at the next summer festival. What can we develop in our workshop and offer for sale?” Such a learning activity is helpful to explore and understand a problem and its background. Very different and creative results can be expected, for example, a garbage can that says ‘thank you’, and a garbage collection robot or an alarm system for depositing garbage. Within this learning design, a prototype of a product that solves the problem is an expected outcome.

7.3 Order-Oriented Task

In order-oriented task implementation, a relatively concrete task is often provided. For example, a waterproof protection for a smartphone is to be built from the existing materials. With such tasks, it is possible to explain why this solution is being sought. Examples of such tasks are:

- Design a cookie cutter for the cookies at the school bazaar as a 3D model
- Design a waterproof protective cover for your mobile phone
- Model your dream house in [13]
- Design and program a game that encourages people to brush their teeth
- Design your favorite t-shirt using a cutting plotter [14]
- Build one vehicle that stops after exactly 2 meters

Compared with the learning activities described before, there is a clear mandate which still allows for a lot of freedom in implementation without a deeper exploration of the background problem. Within this learning design, creative solutions are possible and desired, and a product that fulfils the task is expected.

7.4 Competitive Task

In makerspace settings with children there are sometimes tasks that are implemented with a competitive element, i.e., where the fastest, best, most creative, etc. product or the most responsible student wins. Examples include paper plane challenges or vehicle design challenges. From our perspective, such competitive tasks are questionable and should be avoided or only planned and implemented carefully, as they appeal to and motivate boys far more often than girls [15]. That such tasks or even awards for individual groups were rather detrimental to the entire process across the individual groups also prompted the team responsible for hackathons with teenagers to not do so There are, however, settings in which situations similar to competition arise where, for example, only a single prototype can be further developed for a joint “big” cause. A sensitive approach is necessary in such learning designs so that individuals or groups do not feel like losers in such selection decisions.

Examples for competitive tasks that can implemented in makerspaces for children are:

- Who builds a vehicle that runs as long as possible?
- Who builds the most beautiful plane?
- Who programs the most popular game?
- Who builds the loudest robot?

Gender-sensitive tasks that have a competitive characteristic but are still motivating for both genders include those that have less emphasis on rankings of outcomes and focus on a solution and requires group cooperation. Examples for such tasks are:

- Who/which group build a vehicle that stop after exactly 2.20 to 2.30 meters?
- Who/which group is able to build a plane with old paper and cardboard that flies at least 10 meters?
- Who/which group can build packaging to carry eggs made only from materials found in the forest, so that the egg does not break in a one-meter fall?

Practically, such tasks are similar to the “order-oriented task” described above. Within this learning design, the conditions for the competition must be clearly planned and made known. The results are oriented towards a high degree of competition which also allow for quite unique solutions.

7.5 Guidance-Based Task

In this learning design, all groups or individuals will need to produce the same result and will receive the same instructions. This also means that the scope for creative solutions and approaches is very limited. Guidance-based tasks are used in the making process mainly to (a) systematically introduce new methods or (b) familiarize students with the use of guidance to make this possible in their own projects.

Examples are:

- Build an LED flashlight according to instructions [16],
- Build a DIY projector using a smartphone (Schön, Ebner & Narr, 2016) and
- Build a banana piano with the MakeyMakey kit (Schön, Ebner & Narr, 2016)

Within such a task, the instruction is provided either through written or orally according to a plan. Typically, the results are very similar and a product, according to the plan is a typical outcome.

8. DISCUSSIONS AND OUTLOOK

While our selected activities are perhaps not new for experienced developers of maker education, we see it as helpful to create a clear picture of which activities need to be supported and which diverse implementations are available and the rationale for their implementation. We recognize that we used similar or even same examples across the different learning designs. However, our presentation and conduct of two training programs for future maker educators using this structure and examples was well received and appreciated by the participants. The variety of activities discussed provided participants with insights into the different maker education structures available and their possibilities for promoting a variety of learning aims in additional too obvious issues such as available maker tools and materials and core learning goals, particularly in school settings.

We also see a need to develop a similar overview for example on how to foster the idea of "failing forward" (see Table 1). We have identified some ideas and realizations, such as the "wall of failures" as a conspicuous collection and emphasis that mistakes are useful learning experiences. In our view, dealing with mistakes is rarely explicitly addressed in maker education through supporting activities. With such collections and overviews, we want to enhance the materials to support the design of maker education.

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