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schools eu

Towards Digital Smart, Entrepreneurial and Innovative Pupils

Methodological principles of educational digital fabrication

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What is FabLab Schools EU?

FabLab Schools EU - Towards Digital Smart, Entrepreneurial and Innovative Pupils is a project funded by the Erasmus + Programme, Key Action 2: Strategic Partnerships | School. The project aims to support a sustainable and pedagogical use of FabLab and digital fabrication in education. ICT is already integrated into many teachers' educational practices. However, this project goes beyond the traditional teaching of ICT - as it focuses on digital fabrication and construction with digital technology (including the use of 3D scanning, 3D printers, laser cutters, vinyl cutters, microprocessors, sensors, etc) and how these processes can facilitate the learning and development of 21st century skills for the next generations.

The project has developed innovative approaches and cutting-edge ICT-based methodologies to motivate students to learn and to prepare them for the technology-centred labour market of the 21st century. Specifically, FabLab Schools EU has worked with the following objectives:

- To increase teachers' competences and pedagogical skills in educational digital fabrication.
- To provide pupils with innovative skills and digital competences required in the 21st century.
- To develop methodological principles for digital fabrication in education.
- To present recommendations on how to adapt this approach, as well as for policy formulation to be adapted at regional or national level in European countries.

In order to achieve the set objectives, the project partners from Denmark, The Netherlands, Spain and Italy have worked closely together and carried out the following activities:

- Development of methodological principles for educational digital fabrication.
- Collection of good practices with digital fabrication in education.
- Testing of methods in and across schools.
- Production of a manual and policy recommendations.
- Educational visits in schools and FabLab experiences in partner countries.

In the following sections, the methodological principles are described and explained preceded by an introduction to the topic of 21st century sill and the Design based approach to digital fabrication that was followed in the project.

The methodological principles are an outcome of 2 years of testing and development with teachers. Teachers have participated in 4 workshops over a two-year period, have tested the design thinking and the design circle in their classrooms, and have shared their experiences through an international twinning programme with other participating teachers of the project. All their reflections and lesson learned have been collected and analysed by Aarhus University, who has extracted the methodological principles that are presented in this document.

The methodological principles present a complement to the design circle. Whereas the design circle is a model that can be described in an "objective" and theoretical way (as will be done below), the methodological principles present the design circle complemented with the experiences and lessons learned by teachers.

Every phase of the design circle will be described according to its focus, the its pedagogical principles, and the indicators for success or challenges. These methodological principles will help teachers to understand better the design circle and receive a well-tested background for implemented. Furthermore, also schools, authorities and decision makers can use the outcomes of the testing and development described in the methodological principles in their approach to education and learning.

INTRODUCTION: Education for the 21st century

Pupils of today face a society that is increasingly digitized, globalized and in constant change. Competent workers and citizens in the future are individuals that can learn and adapt to new knowledge - alone or in collaboration. As a consequence, the objectives of education are no longer just what you learn, but how you learn it, and what you can do with what you learn. It becomes important to “learn how to learn” and to ”create new solutions to new problems”. This is the discussion on the “21st century skills” - of which skills are needed to navigate through future challenges.

There is no set definition of 21st century skills, but they are generally defined as the skills and competencies young people will be required to have in order to be effective workers and citizens in the knowledge society of the 21st century. Inspired by OECD and the research undertaken by Aarhus University, the FabLab Schools EU project has worked with six main skills needed in 21st century life, work and education:

- Critical thinking
- Communication and collaboration
- Creativity and innovation
- Complex problem solving
- Technological mastering
- Digital Citizenship

Critical thinking is about dealing with the world in a problem-solving way, to analyse, evaluate, and clarify questions.

Communication and collaboration: Communication is not just about talking - it is also about listening. To express ideas, to use different platforms and to apply different ways to express yourself.

Collaboration is about participating equally in different kinds of processes, about accountability and being open minded towards new ways of collaborating.

Creativity and innovation relates to skills in creating, innovating and being diligent. Think inventively, learn from your experiences and see opportunities.

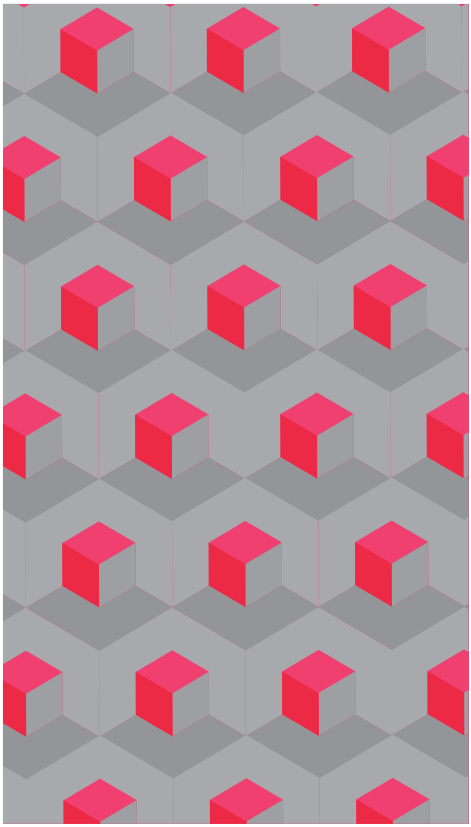
Complex problem solving relates to skills used to solve novel, ill-defined problems in complex, real-world settings.

Technological mastering is about using well-known technologies in new areas, and generally using technology to increase your possibilities for action.

Digital Citizenship focuses on enhancing the ability of individuals to act and act as citizens in a society of ever-increasing technology.

Teachers hold the key to elementary and secondary schools' contribution to continuous growth and prosperity in the EU. At the same time, teachers play an important role in raising children's and young people's understanding and critical reflection concerning the increasing digitalization of society.

Educational institutions need to develop students understanding and mindsets for such a future, by engaging them in processes of constructing with new forms of digital technology, such as digital fabrication tools, microcomputers and programming software as a means of making them agents in the design and development of their future.



Digital Fabrication and Design Thinking in Education

Design thinking and digital fabrication is increasingly being integrated in primary and secondary education as way of addressing 21st century skills. Digital fabrication involves the design and manufacturing of products using advanced technology. The digital technologies enable students to work with knowledge production and construction at a new level, where insights, values and ideas can be manipulated digitally and materially. The digital tools enable them to visualize ideas in an instant -- be it a city of the future, an idea for a product, or the reconstruction of history. Moreover, it strengthens their entrepreneurial spirit because the technologies enable them to create and envision new solutions and concepts for the world around them. Design thinking is an approach to innovation and complex problem solving based on design theory and practice. It is used widely by designers across industry and academia to develop relevant solutions through iterative and creative processes of design and innovation.

There are several good reasons for working creatively with design and technology in the way this project has done. First, focusing on the intangible outcomes of design, such as new skills, new insights, and a reflective stance toward technology, can empower students to become part of co-creating our future society. Through collaborative making and problem-solving activities students learn

about critical thinking, complex problem solving, digital citizenship and collaborative skills. Pupils of today face a society that is increasingly digitized, globalized and in constant change. Competent workers and citizens in the future need to learn and adapt new knowledge - alone or in collaboration. As a consequence, the objectives of education are no longer just what you learn, but how you learn it, and what you can do with what you learn. It becomes important to “learn how to learn” and to ”create new solutions to new problems”.

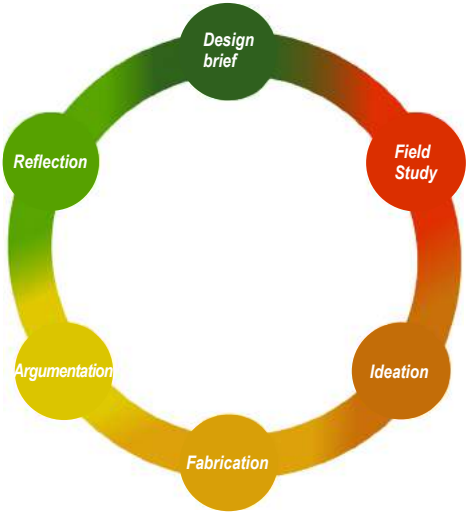
Second, in the European context the societal challenge of preparing young people for a digitized society is high on the political agenda. The notion of twenty-first century skills is an attempt to articulate the skills needed to succeed in a highly globalized and digitally mediated society. Some of these skills are closely related to children’s abilities to create with digital materials and also solve complex societal problems, even if such competences are not necessarily new.

Prof.Paulo Blikstein who founded the global FabLab@School concept at Stanford University argues that the rapidly extending reach of digital fabrication technologies is a “democratization of innovation” that emphasizes the possibilities for including children in the design of new technologies by introducing those technologies into formal education.

The FabLab Schools EU approach to design thinking and digital fabrication is informed by Scandinavian participatory design and has been developed in the context of the Danish FabLab@SCHOOLdk project (2013-2017) by Aarhus University. Within the FabLab Schools EU project this approach has been developed into a European educational setting integrating innovative technologies and teaching methodologies in and across diverse educational subjects and contexts. It has been the intention of the project to demonstrate the viability of such technology and approach for educational purposes and contexts in Europe as a whole.

A Design Based Approach to Digital Fabrication

Figure 1. The design process model for digital technology in education.



To support the process of explorative learning the partnership has employed a design process model to support students' and teachers' work through the entire design process (see Fig. 1). The model is based on six main activities. The circular model illustrates design as an iterative process, since all design outcomes eventually lead to new insights, questions and new problem framings. Iterations occur within and between each of the activities and with increasing experience, eventually crisscrossing effects are created where students use the model as a framework for navigating through their own design project.

The model is designed to facilitate and support students' as the main protagonists throughout the design process. First, the design model supports an ongoing interplay between divergent and convergent thinking and doing, which compels students to open up their design process and take in new perspectives and subsequently deselect aspects in their efforts to reach a meaningful design solution. This demands high levels of group collaboration, commitment and agency from the students. Second, the design model incorporates argumentation and reflection as the closing activities of each iteration. By positioning reflection as the outcome of the design activity, students develop a reflecting stance toward technology and design, over time.

The design model does not prescribe either specific actions or project measures, but merely indicates how the design process develops. This is to encourage the students to be mindful about their process, their collaboration, and their choices during the process, rather than

focusing solely on the tangible outcome of ad hoc ideas. There are no formal instructions in the model, which increases the self-efficacy of students to navigate through the stages of project framing, research, ideation, and fabrication to the final stages of argumentation and reflection. They have to stay in charge of the design process while they gradually explore the design brief and activities provided by the design experts.

This approach to design and technology in education addresses how we enable students and educators to develop critical and nuanced understanding about digital technology and provide them with the skills and competences for engaging with future digitalised society. The approach is operationalized in the activities of the design process. In the FabLab EU project the model was used as a basis to (1) develop courses and in-practice experiments with students in different educational settings in Europe (see chapter Teachers' projects), and (2) to develop methodological principles based on practical experiences that would make our experiences beneficial to a wider audience (see chapter Methodological principles).

An Iterative Design Process Model

The model contains six main design activities, each including several sub-activities: *(1) the design brief*, for framing a complex or real-world challenge and for planning the design process; *(2) field studies*, to explore and research the context and users as well as existing knowledge of the subject; *(3) ideation*, for the creative development of ideas using various techniques and materials; *(4) fabrication*, for mock-up and prototyping of concepts using digital technologies and analogue materials; *(5) argumentation*, for testing a design concept or product and reflecting on the design moves and arguments of the process; and *(6) reflection*, for reflecting on the learning outcome - or design competence - developed through the entire design process.

The activities support students' and teachers' ability to work through an explorative design process while gaining an understanding of the potential value of design thinking in learning processes. The model is comparable to other generic design process models but integrates several dimensions that are central for the educational context, such as field studies to explore and research real-life problems, and argumentation and reflection to develop students' reflective skills and design competence.

The model can be used as a tool through which students engage in cultural production by producing novel digital artefacts and

solutions for meaningful practices and complex challenges. The model allows students to navigate through an iterative and explorative process according to their focus and interests within a given design challenge. The framework allows students to develop a set of design skills and competences through reflection, synthesis and hands-on design work towards co-creating intentional change. As such, the model can be used as a reflective tool for developing students' agency as critical co-creators of a digitalised society.
Overall the model can help develop students' competences for:

- Iterative and explorative design thinking
- Real-world and dilemma-based learning
- Integration of physical and digital materials
- Developing a language of design and innovation
- Critical argumentation and reflection
- Divergent and convergent thinking

Design Brief and Field Studies

The first activities engage students in a contextual approach for working with real-life challenges and the development of possible futures. The process model emphasizes critical engagement with the design challenge, framing and prioritizing the focus from a larger field of possibilities. Based on an initial understanding of the design problem, the design brief, students move through research and field studies to explore relevant contexts and user groups and generate empirical data and insights for the following activities of ideation and fabrication.

Important learning aspects of these activities are exploring and prioritizing particular issues of a complex situation, using one's prior knowledge, values and experiences to ask questions and engage in a process of framing and reframing both problem and solution. Often teaching practices do not emphasize the contextual aspects of understanding and framing a specific problem, but rather treat problems as predefined or something to be discovered. Our approach emphasizes the ability to address complex and real-life challenges and the ability to explore, analyse and synthesize relevant forms of digital and cultural production in response to these.

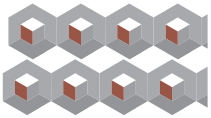
Ideation and Fabrication

Ideation and Fabrication cover activities that are often referred to as sketching, conceptualizing, mock-up, prototyping, implementation and testing. Here, focus is placed on the students' ability to externalize ideas in ways that allow them to further explore and transform these into working concepts. In ideation, there is a wealth of existing design tools and techniques that allow for the collaborative exploration

and communication of ideas and possible futures. These activities challenge students to transform abstract ideas into tangible representations and scenarios, and to work with the integration of diverse analogue and digital materials.

The availability of different design materials helps students to develop diverse solutions, and to select the most promising and relevant ideas for the specific challenge at hand. The fabrication activities are characterised by iteratively exploring, implementing and testing design ideas. Students learn through making and problem solving. They learn to collaboratively work with design ideas and develop technical skills and competences that are necessary for working creatively with digital technology. Thus, ideation and fabrication combine hands-on making with reflective thinking through concrete problem solving and innovative solutions.

Argumentation and Reflection



The final two activities of argumentation and reflection are central to our approach to design and technology. They cover the ability to develop arguments and reflections about the digital artefacts and learning outcomes of the design process. In argumentation, students present their work and receive feedback from peers and external partners, communicate and test the intended use of the artefacts. Through this process they reflect upon and develop a language about their decisions and priorities through the process. Based on these collaborative activities, students may modify and develop their products and refine their arguments in relation to the requirements of the design brief. Such reflections can be based on insights developed through the process, about the problem, specific user groups, technological constraints, etc.

The final activity of reflection involves collaborative and personal reflections on the learning outcomes of the iterative design process, the creative work with technology, and real-world problem solving. The focus is not on formal assessment of students' instructional learning, production of aesthetic objects or technical skills. Instead, qualitative indicators of the students' development of design ability, digital literacies and understanding of work with digital technology and design as interconnected practices are emphasized. Students can reflect on their subject learning, or personal learning from the design process, setting targets for future work. They can also assess learning outcomes in relation to their ability to judge the relevance and impact of technological solutions for specific people, contexts and concerns.

As students and teachers become more familiar with the approach to design thinking and digital fabrication, they are able to navigate more freely between different activities and phases in the model. As such, the design process model emphasizes the entire process, from research, ideation, and mock-up creation to the initial presentation of a prototype, argumentation for design ideas and reflections on the learning outcomes and possible societal impact of the ideas.

A Framework for Designing the Design Process

When planning each phase of the process model, teachers should work with connections between:

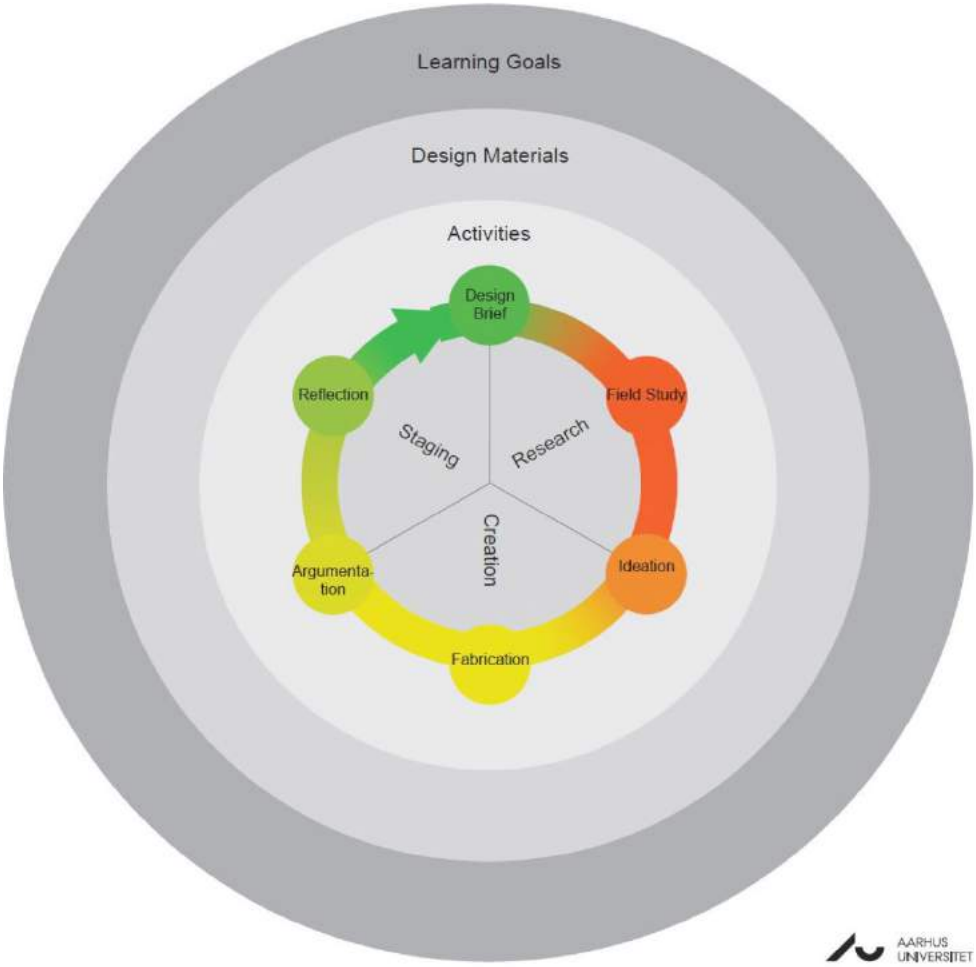
- Learning goals
- Design materials
- Activities
- Assessment

1. What are the learning goals or outcomes for the students ?

2. What design materials do you create/provide for the students?

3. What design activities do you scaffold the students' design process?

4. How will you evaluate and assess the students work and process?



AARHUS UNIVERSITET

Assessment of process, product and learning outcomes

There are many ways of assessing a project according to the teacher's focus on learning, the design challenge, the students capabilities, the length and ressources of a project. Here are some general points of evaluation concerning the design challenge, process, product and learning outcomes.

Design challenge - a Real-Life Problem:

- *How did students work with framing and reframing the design challenge?*
- *Were the students motivated by the design challenge and able to identify directly with it?*
- *To what extent has the design challenge given insight into and reflections on societal challenges?*

Process:

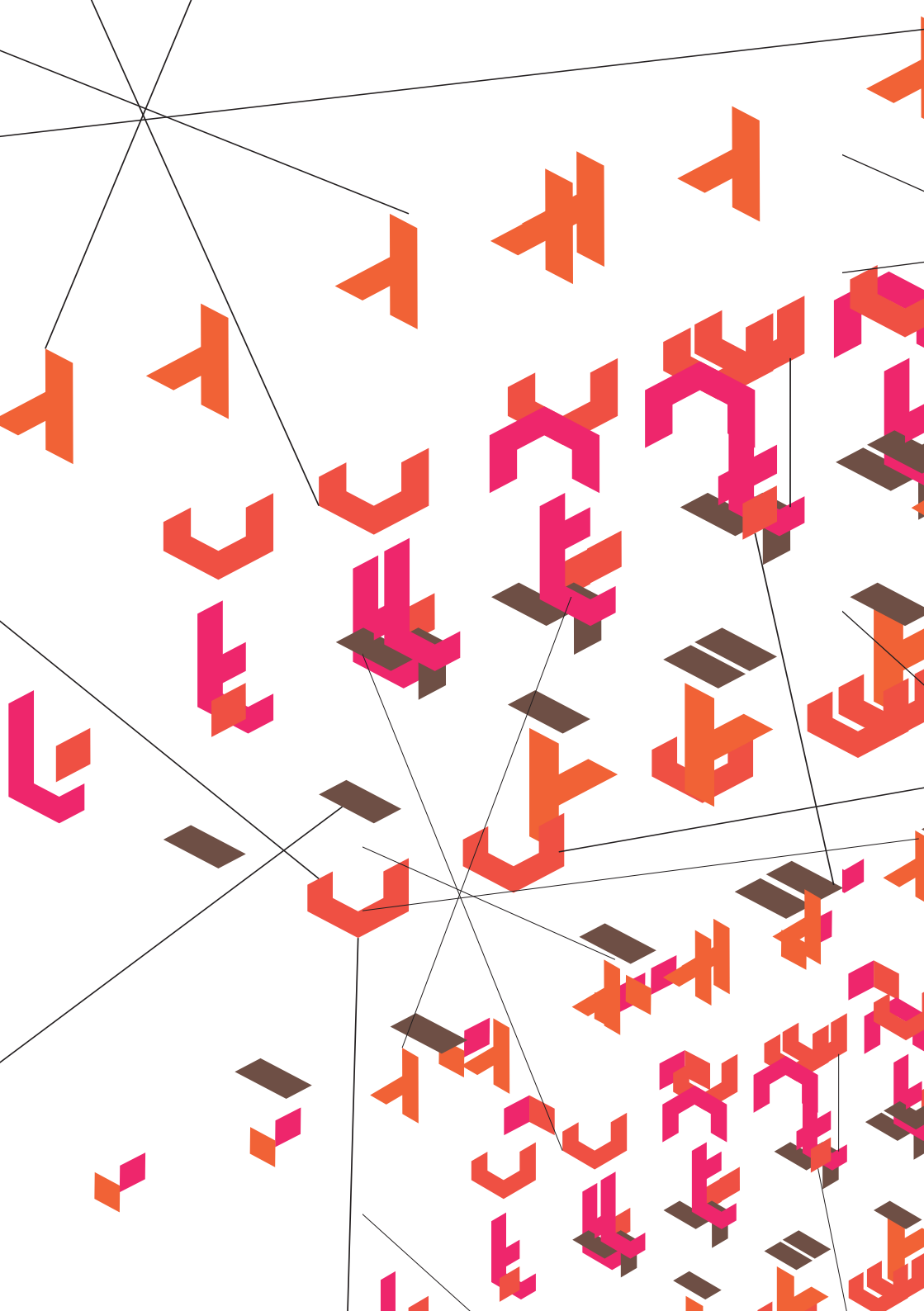
- *Which activities and phases were the most successful and challenging for the students and why?*
- *What breakdowns happened in the process and with what results and learning outcomes?*
- *To what extent are students developing skills and competences related to the design process (e.g. exploration, language, judgement, reflection, etc.)?*

Product:

- *To what extent did the students manage to develop and externalise their ideas?*
- *What materials and technologies were integrated into the solution and what successes and challenges were there?*
- *How well did the students' proposals for a solution relate to the design brief and challenge?*

Learning:

- *What kind of learning outcomes did the process give everyone involved?*
- *Where did the most interesting learning outcomes arise - for students and teachers?*
- *How were learning outcomes assessed during and after the process?*



Methodological Principles

The aim of the project has been to develop a methodology for teaching and learning with digital fabrication and design – a method with principles that facilitate learning of 21st century competencies across European countries. In the following, the concrete methodological principles are presented. The chapter briefly presents an extension of the design model as a practical framework for teachers' planning, giving attention to learning activities, design materials, learning goals and evaluation. Followingly, the focus and pedagogical principles for each phase of the design process are presented as guidelines for teachers working with the design circle. In addition, a selection of the most important success criteria and challenges are presented for each phase of the process.

Design brief

Focus of the phase:

- Frame and explore the design challenge and choose to focus within a larger field of possibilities.
- Plan the design process, roles, resources, and constraints.
- Create space for understanding and learning about the design task at hand.
- Concretising the design challenge to a set of questions or areas to be explored.

Pedagogical principles:

- Plan enough time for this process so that students get an understanding of the complexity of the design brief. Create transparency about student roles, subject requirements, expectations and deadlines.
- Involve student preunderstanding. Examine concepts and disciplines so that everyone has the same set-off to solve the tasks and speaks the same «language»
- Continuously review the different phases of the design circle so that students are trained to create the best possible ideas and solutions. Train a holistic approach with the students.
- Use different materials and educational approaches so that students get acquainted with both analogue and digital tools in each phase.
- Train collaborative learning methods along the way, so that students' different competencies and knowledge are brought into play. Teach students to ask curious questions, train critical reflection and documentation so that a progression occurs in student learning.
- Train peer-to-peer learning. Teacher-to-teacher, student-teacher and student-student.

It is a success when:

- The design brief is realistic and meaningful for the students.
- Students can understand how to address the challenge by using the design circle as pedagogical framework.
- Students through motivation and commitment can work together to find the best possible solutions to the task and take responsibility for their personal role during the process.

It is a challenge when:

- The design brief does not make sense for the students because it is too open, complex or irrelevant.
- There is not enough time for students to immerse themselves in the task, so they do not work on the basis of the same language and knowledge.
- There has been not enough elaboration put into the different phases of the task, so that the meaning of the whole will disappear.

Field study

Focus of the phase:

- Understand the context and problem field of the challenge: what is the context, who are the users, what are their need or challenges, etc.
- Research different sources of knowledge and data on the subject(s).
- Observe people's behaviour, make relevant questions, find themes and challenges that are relevant for the design challenge.

Pedagogical principles:

- Use different methods - including interviews, photo safaris, user surveys, etc. to work with field studies.
- Create a collaborative environment where everyone sees the value of using each other's personal and subject knowledge and experience. Be aware of working with possible prejudices.
- Give students a broad knowledge of various analogue and digital tools and their applications
- Train the development and analysis of empirical data with the students so that they are able to transform knowledge from this phase to the idea creation phase.
- Help each other (both teachers and students) to find the insights and challenges that create the best solution to the design brief.
- Challenge the students' to step outside their comfort zones. Create a learning environment where courage and perseverance are encouraged.

It is a success when:

- When students use empirical data and insights to create ideas for solving their tasks.
- Students dare challenge themselves and are curious about the users' opinion and knowledge.
- Students know their role and work based on the same preconditions.

It is a challenge when:

- Students have to work with tasks that move them out of their comfort zone.
- Students do not understand the importance of using field studies to generate new knowledge, but find solutions based on their own assumptions and fail to transform individual knowledge into group collaboration.
- Students are not retained in field study work, but quickly move on to the idea phase.

Ideation

Focus of the phase:

- Create many ideas based on the insights, needs and opportunities of the design challenge and field studies.
- Work creatively with and integrate diverse materials, tools and methods for ideation.
- Systematize ideas and insights and choose the/those idea/ideas that best match the design challenge.

Pedagogical principles:

- It is important to use different educational methods and materials to generate ideas; LEGO, clay, pictures, scroll cards, paper, scenarios, etc.
- Give students the tools and structure to give and receive constructive feedback on their ideas
- Set a maximum number of ideas, but let students create enough, so there are many to choose from. Find a good balance.
- Make specific exercises that train divergent and convergent idea generation
- Teach students to pitch their ideas in front of different audiences. Use different forms of communication and feedback.
- Encourage students to create ideas together and alone. Create an environment where students build on each other's ideas and make them visible to everyone.
- Create a learning environment where the skewed and wild ideas are possible.

It is a success when:

- Students can generate several ideas, are open to the ideas of others, and can change their own perspectives.
- The students are inspired by using different materials - both for mock-ups and for the final design.
- Students can transform knowledge from a field analysis to this phase.

It is a challenge when:

- Students have let go of their first or immediate idea and change perspective.
- Students have difficulty receiving, processing critically and are unable to see opportunities.
- Students have to use insights and ideas from field analysis that are not necessarily their own personal ideas and wishes.

Fabrication

Focus of the phase:

- Externalise ideas and concepts into mock-ups, prototypes and products.
- Select analogue and digital materials to transform ideas to prototypes and products.
- Work creatively and exploratively to construct with different fabrication technologies.
- Visualise and represent artefacts in various ways while continuously adjusting.

Pedagogical principles:

- Give students a basic knowledge of the different technologies and their limitations, so that students are able to make qualified choices for the fabrication phase
- Make sure everyone knows what roles they are going at play in this phase and who has the necessary skills to perform the roles in the group.
- Make mock-ups early in the process, enabling students to make adjustments along the way before the final fabrication.
- Put creativity and experimental action into play - both with analogue and digital tools.
- Practice basic skills and competences along the way and «push» student comfort zones.
- Train students to see that there may be several possible design solutions.

It is a success when:

- The students manage to transform an analogue design into a digital product or artefact.
- Students can apply the possibilities and limitations of the digital technologies.
- Students experience the value of the different phases and use knowledge from these in product fabrication.

It is a challenge when:

- Time, number of students and language skills limit the optimal use of technology.
- Students lack the curiosity to immerse themselves in product fabrication and do not take individual responsibility for the process.
- Students do not have the basic practical skills in place to carry out the tasks.

Argumentation

Focus of the phase:

- Judge the quality of product and process, and create connections between the design challenge, the students' focus and final product.
- Test and evaluate the design outcome in context with users and stakeholders.
- Find arguments for strengths and challenges as a result of design moves and decisions in the process.
- Develop a language to describe the movement between phases, and from e.g. mock-up, prototype to final product.

Pedagogical principles:

- Make sure that all students play a role in the argumentation phase.
- Make mock-ups early in the phase, so students can try again and again before finalizing.
- Students should have a basic knowledge of different technologies so that they can argue for the final choice and solution.
- Give students tools that support them in constructive feed-forward and feed-back in the work on the design task.
- Focus on students' development of a language that enables them to describe their design process and outcome.
- Create a learning environment from start to finish, where security, trust and mutual respect for diversity are important values.
- Give students a scaffold on how to train a good presentation and let them pitch their ideas and presentations to others before the final presentation.

It is a success when:

- Students are able to engage in dialogue with each other, receive feedback, adapt their product accordingly, evaluate their work along the way, and reflect this in the argumentation.
- Students are able to argue how the finished product supports the design brief and the set learning goals.
- Students are able convey their presentation in a language so that everyone retains interest.

It is challenge when:

- Students do not demonstrate collective ownership of the design process.
- Students do not work constructively to provide and receive feedback, see the value of their mistakes - and acknowledge their mistakes.
- Students are unable to argue for their choices so that other students may understand these, ask relevant questions and express wonder in ways that take learning to another level.

Reflection

Focus of the phase:

- Create reflection on learning outcomes for both process, product and set learning goals.
- Reflect on strengths and limitations, including reflections on how learning happens through the design process and between phases.
- Create collaborative dialogue and feedback that bring learning outcomes forward to other projects, subject and contexts.

Pedagogical principles:

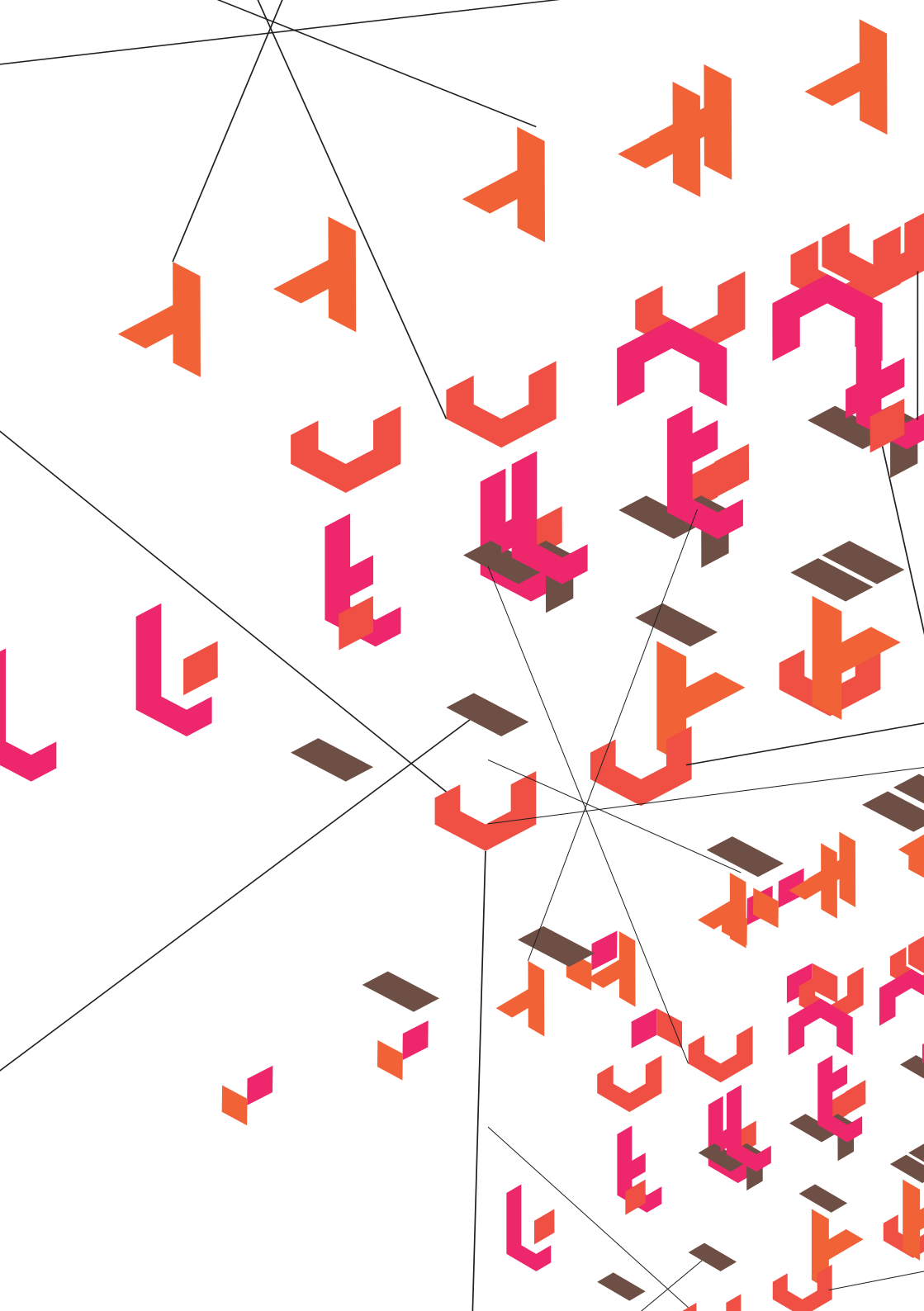
- Students must, from the first lesson, document their process by e.g. logbooks, videos, etc.
- Teachers should allow students to reflect critically on experiences and decisions after each phase in the design process.
- Encourage students to learn from their mistakes and use them constructively for improvements.
- Teach students about the importance of bringing different skills into play and that everyone acquires knowledge in different ways.
- Have students reflect on the importance of working collaboratively.
- From the first lesson, the students should acquire and train concepts and get a common language which will be important for the reflection phase.
- Show and have students train how they can bring knowledge from the work on the design brief into different subject areas.

It is a success when:

- Students can reflect on what worked best in each phase and in the design process as a whole.
- Students are motivated to test and improve their solutions so that both the overall process and the product produce the best possible outcomes.
- Students are able to see how what they have learned may be used in other subjects and courses.

It is a challenge when:

- Students are not able to work constructively with mistakes and criticism.
- Students are not able to see how the design brief, the product and the process are connected.
- Students are not able to reflect on their own role but instead blame others for lack of success.



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