Towards Digital Smart, Entrepreneurial and Innovative Pupils
A Manual on Teaching and Learning with Digital Fabrication

«Tinguely» project.
The project FabLab Schools EU: Towards Digital Smart, Entrepreneurial and Innovative Pupils has been co-funded under the Erasmus+ Programme KA 2 – Strategic Partnerships |School. Project Number: 2016-1-DK01-KA201-022298. ©FabLab Schools EU Project Partners
«House of words» project.

«Tinguely» project.
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.

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.

The project focuses on the 21st century skills that children and young people need to acquire to be prepared for the 21st century and the future digitalized society. These include education in innovation and social entrepreneurship, which will prepare them for future job opportunities in a constantly changing labour market.

The project aims to increase teachers’ competences and mindset towards learning and teaching with digital technologies, addressing the needs of developing the competences of educators as highlighted by the European Commission (European Framework for the Digital Competence of Educators - DigCompEdu - JRC Science for Policy Report - EC, 2017). The project links this understanding to specific methodological principles that will make it easier for teachers and educational programs to make digital fabrication part of their educational practice.

The partnership consists of four countries and five organizations:

- The municipality of Vejle (Denmark) as coordinator,
- Aarhus University (Denmark) as academic partner,
- LABoral Centro de Arte y Creación Industrial (Spain),
- Vereniging Ons Middelbaar Onderwijs (The Netherlands)
- and Centro dello Sviluppo Creativo “Danilo Dolci” (Italy).

In the following section the partners introduce themselves and their interests in the project.
Contribution from FabLab@SCHOOLdk

The Danish team in FabLab Schools EU has been committed to learn from and contribute to the transnational learning partnership. The Danish participants are part of the FabLab@SCHOOLdk project, which has been developed in collaboration between the municipalities of Vejle, Silkeborg and Kolding, Aarhus University, and partner businesses since 2013. The project is part of the FabLearn Labs Network of Transformative Learning Technologies Lab (TLTL) at Stanford University.

FabLab@SCHOOLdk is organized differently in each municipality, but every municipality has established at least one central FabLab and help schools from the municipalities to establish their own local FabLabs. The FabLabs work based on the same approach and principles to digital fabrication and design and share equipment and technologies in order to easily facilitate sharing of knowledge and evaluation both nationally and internationally. Based on research results and collaboration with Aarhus University, each member municipality develops teaching and educational materials which they assess and publish on www.fablabatschool.dk.

Inspiration from international partners is very important to the Danish partners in FabLab Schools EU. At the annual FabLab@SCHOOLdk conference (FabLearnDK) teachers present their teaching experiences and the goals for FabLab learning to a broader community of educators, leaders and politicians. At the conference, international researchers present the latest findings and knowledge within the field, nationally and globally.

FabLab@SCHOOLdk is a platform and a network in which teachers from all over Denmark can find and share knowledge, inspiration and training for innovative education for pupils. The work is meant to inspire pupils to use new digital technologies and to give them skills, courage, and the desire to experiment with developing solutions to real-world problems.

Focusing on digital fabrication and design thinking, FabLab@SCHOOLdk aims at preparing pupils for an ever-changing, digital future by the development of 21st century skills: Critical thinking, communication and collaboration, design and innovation, complex problem solving, ICT-competences and digital citizenship. Digital fabrication is the next generation’s IT where IT is used to produce physical objects. Programming tools (eg 3D programming), 3D printers and laser cutters are technologies that pupils learn to use to design and fabricate products in a FabLab.

Through hands-on experience with digital making the pupils not only use technology, they become able to understand technology beyond the consumer’s cage. In experimental learning environments pupils can evolve as individuals through learning how to express themselves, using the same digital technologies that increasingly make up the setting of their daily life. In doing so they will be able to play an active role in shaping their future.

Aarhus University

Design Thinking and Digital Technology -Research and Development of Education for the 21st Century

Aarhus University (AU) is a Top 100 university with the vision of contributing to the development of national and global welfare via outstanding research and world-class degree programmes. The AU mission is to ensure and develop knowledge, welfare and culture through research and research-based education, knowledge dissemination and external service. In all degree programmes, research and education are closely related. As a comprehensive university with more than 11,000 full time employees AU is organized into 26 interdisciplinary departments and four faculties: Arts, Science & Technology, Health Sciences and Aarhus School of Business and Social Sciences. In recent years AU has been moving up the most important university ranking lists. In 2016 the university was number 65 at the Shanghai Ranking (ARWU), and number 98 of 17,000 universities on the Times Higher Education World University Ranking (2016).

The School of Communication and Culture (SCC) (http://cc.au.dk/en/) belongs to the Faculty of Arts and has 5,000 full-time students as well as 160 full-time employees. The School offers a broad range of research and degree programmes across a variety of fields: literature(s), information and media studies, linguistics, Scandinavian Studies, Western European languages and cultures as well as the arts and aesthetics. The Department of Digital Design and Information Studies is a prominent department of the SCC, hosting i.a. the interdisciplinary research Center for Participatory IT (http://pit.au.dk), with strong roots in the Scandinavian tradition for Participatory Design (PD), which combines the areas of technology development and use with a broader interest in participative practices at the workplace and as part of people’s everyday life.

The FabLab@School.dk (2013-) project is a research project studying how children develop their design literacy through processes of digital fabrication and construction in curriculum-based education. The project has been developed in close collaboration with the Danish municipalities of Vejle, Silkeborg, Aarhus and Kolding, and has formed the basis for further research in the FabLab Schools EU project. The FabLab Schools EU project has provided opportunities to develop and evaluate the methodological approach to design thinking and digital fabrication in a cross-national setting and develop new agendas for research and practice in the field together with engaged European partners. These and other research agendas are being developed in the interdisciplinary research centre for Computational Thinking and Design.

The Center for Computational Thinking and Design (CCTD) (http://cctd.au.dk/) is a new interdisciplinary center at Aarhus University. The center has the School of Communication and Culture, the Department of Computer Science and the Department of Management as the primary actors. The vision for the center is to further develop the
research and educational perspectives on basic IT competencies - the “21st century learning skills”. This work is ongoing, and focuses on all levels of education in Denmark, from primary education to university level curriculum. The research calls for new perspectives on IT education within programming, digital fabrication, digital innovation, design studies, digital methodology amongst others. The center works with these perspectives across educational contexts within the humanities, the social sciences and the natural sciences.

Related research publications:


LABoral Centro de Arte y Creación Industrial

The contribution of an art centre to the educational system of the 21st century

LABoral Centro de Arte y Creación Industrial (http://www.laboralcentredarte.org) is an institution quite extraordinary in the Spanish context of art centres. Committed to contemporary artistic practices, LABoral is fundamentally devoted to digital culture and to the cross-field connections among art, science, technology and society. Launched in 2007, the centre’s main goal is to produce and transmit new narratives and imaginaries of 21st century society to a wide audience, through exhibitions, educational programmes and other research and training projects. At present, most of its activities take place in the audiovisual and sound laboratories, as well as in the digital design and fabrication labs, which are all open to a heterogeneous community of users, including artists, researchers, entrepreneurs, teachers and students from primary and secondary schools in Asturias.

By introducing young people to critical and creative approaches of the digital world, LABoral also motivates teachers to use digital tools, placing special emphasis on new methodologies and ways of relating, communicating, managing and guiding the process of learning. Indeed, it is not sufficient to merely switch blackboards for digital screens or notebooks for computers and tablets. Their use introduces teaching dynamics that are quite different from those teachers are traditionally familiar with. Even the connections among different areas of knowledge are structured in another way. Instead of transmitting knowledge in a compartmentalized way, in many areas today there is a need for close interfaces and cross-field connections to take on the complexity of the realities facing the youngest generations of the digital age.

Well aware of these challenges, for over five years, an interdisciplinary team of artists, educators and technicians from LABoral Centro de Arte, in close collaboration with the Regional Ministry of Education and Culture of Asturias, and the primary and secondary schools throughout the Principality, have carried out workshops in various formats related to the audiovisual world of television, design and digital fabrication, creative programming, robotics, virtual and augmented reality and citizen science. These workshops are included in the school curriculum in an interdisciplinary, inclusive manner. Their objectives are different from traditional art or technology classes because the skills and methodologies inherent to them do not constitute an end in themselves, but rather a means to transmit other experiences and knowledge included in the curriculum. The common denominator of these workshops is project-based work and cross-field creative integration of different areas of knowledge in the learning process. These experiences are carried out with critical and creative methodologies derived from both artistic practices and technological culture. The latter is related to collaborative open source dynamics and the premise of learning by doing, both fundamental to ‘maker culture’. The commitment to education by LABoral Centro de Arte y Creación Industrial is based on the conviction that art is a highly effective interdisciplinary educational
tool for new learning processes and the overall development of young people. Like no other, artistic disciplines equally stimulate emotional, conceptual and affective development. Their practice fosters a sharpening of the senses, manual dexterity, and the development of all types of cognitive competencies. In fact, the cross-field nature of artistic practices, especially since the beginning of the 20th century, has increasingly fostered reticular connections among ethics and aesthetics, linguistics, technology and communications, mathematical and spatial applications, as well as others related to the social and natural sciences. What is more, these stimuli foster not only creative critical thought but also communication and more collaborative and socializing attitudes among classmates, as well as more collaborative and socializing attitudes among classmates. What is more, these stimuli fostering also communication and more collaborative and socializing attitudes among classmates.

The experiences and knowledge acquired collectively among the different agents who constitute the educational community in Asturias was a determining factor in taking a further step and sharing it with the other educational community in the eastern centre of Asturias, is a determining factor in taking a further step and sharing it with the other educational community.

C.P. Ablaña-Pereda is located in a small town in the central mountains, in an economically and socially depressed area, where 60% of the population are Gypsy families. It is the only school among all the participants that has a small FabLab, with a 3D printer and vinyl cutter.

These four institutions represent an educational ecosystem that brings together quite diverse contexts, practices and knowledge. That is precisely why their contributions make this collaboration enriching. Although each of the four centres have also participated in prior educational experiences with LABoral, this is the first time these four centres from Asturias are connecting agendas and engaged and committed to integrating a European approach to the use of FabLabs in new community educational scenarios.

Colegio Andolina is an authorized primary school in the city of Gijón, which arose from a cooperative of families and combines the pedagogies of Montessori, Pestalozzi, Freinet, Piaget, and Rebeca and Mauricio Wild.

I.E.S. Peñamayor, located in the rural area of the eastern centre of Asturias, is an integration centre that teaches ESO and Bachillerato secondary education classes to a highly diverse student body, some with special educational needs and profiles.

C.P.E.B Cabañquinta offers obligatory pre-school, primary and secondary education. The centre, with a bilingual education programme, has participated in various European projects, which gives its students, who are from middle and lower middle class families, new learning opportunities.

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In the Netherlands, the participating partner in the FabLab Schools EU project is the Theresialyceum (https://www.theresialyceum.nl). This is a secondary school in the city of Tilburg. The school prepares students for higher vocational education and university education. Within the city of Tilburg the school stands out with a special program for highly intelligent students and an emphasis on cultural education.

The Theresialyceum is part of a community of 34 local schools called, Ons Middelbaar Onderwijs (OMO).

It is becoming increasingly difficult to predict which knowledge and skills the current generation of pupils have to master in order to be successful later on. To provide future-proof education and match the future needs of pupils, the school is constantly evolving. The school’s strategy plan is based on two basic principles, the educational vision of the Dutch government (education plan 2032), and the 21st century skills.

In the new interpretation of the schools strategy plan three continuous themes are defined, namely: developing self-reliance, talent development and citizenship. Self-reliance can include adopting an investigative attitude, (self-)reflection, discipline, making choices, working together and media literacy. Developing self-reliance must be at the core of the education of our school. Talent development at our school is expressed in the provision of extra modules and courses and attention to personal development. Citizenship means, among other things, paying attention to social involvement and internationalization. All these elements are expressed in the three pillars of the school: People & Culture, Language & Communication and Nature & Technology.

Within the pillar Nature & Technology there has always been a desire to be at the forefront of development. In the past, a Mini-FabLab has been set up with the enthusiasm of one of the technology teachers. The aim has been to introduce students to new digital fabrication tools and prepare them for the future in this way. The Theresialyceum is the only school in the region that has its own Mini-FabLab. Reflecting on the developments of the school’s strategy plan, we have come to realize that having digital fabrication tools available merely for innovation no longer suffices to provide future-proof education. Rather, we want the Mini FabLab to be an instrument that is used, outside the technology courses, to achieve the new educational objectives and to develop students into digitally smart, entrepreneurial and innovative students. Hence, using the Mini FabLab as an instrument to teach pupils a problem-solving attitude, it must be part of a didactic model and approach, which enables each department in the school to work in a structured manner.

The FabLab Schools EU project aims to develop a common methodology for the use of a FabLab as an instrument for the formation of creative, entrepreneurial pupils. This fits well with our goals. Within this project the development of didactics plays into our strength. We are also an example of a school where the movement towards using a FabLab as a means of providing future-proof education according a structured methodology is realized, from the perspective and initiative of teachers. Through this bottom-up approach, we hope to show how this change can be realized while retaining the ownership of the teacher. We hope to inspire other schools to follow this example.

**Related research publication:**


**LABoral Centro de Arte y Creación Industrial,** Gijón.

**Theresialyceum**

Digital fabrication as an Instrument for Future-Proof Education.

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The Centre for Creative Development “Danilo Dolci” (www.danilodolci.org) is a non-profit association based in the south of Italy (Palermo), which focuses on innovative practices and education. Therefore, digital fabrication in schools is a vital element to bridge the two areas of its activities, especially since FabLabs in Sicily are only little developed. CSC Danilo Dolci collaborates with many local schools in Palermo, offering them opportunities to improve and develop their educational program. The technical, transversal skills and other soft skills that are developed with FabLab education are of great value for children’s education and the development and improvement of the educational system, especially in Sicily.

In the south of Italy, FabLabs, design thinking and digitalization are spreading at a slow pace. Despite the fact that since 2011, FabLabs started to come to life in Italy which led to the current situation of about 170 FabLabs in all the country, most of them are concentrated in Italian northern regions. In Italy, the adoption of FabLab in education programmes is still sporadic. Even though FabLabs often organize special courses for school students, they have not been considered yet as part of the educational programme or curriculum. The Italian government acknowledges the benefits and growing importance of FabLabs in the policy “Piano Nazionale Scuola Digitale (PNSD)” (National Plan for Digital Education 2016), which has been launched by the Ministry of Education, University and Research aiming at the development and implementation of a comprehensive innovation strategy across the Italian school education system to push it further into the digital age. It is a fundamental pillar of the recent Italian school reform law “La Buona Scuola” (The Good School, law 107/2015)². This strategy includes investments in the upgrading of schools by introducing new equipment and this is slowly but steadily changing the look and the quality of schools’ educational offer. On a regional level, these types of governmental support led to Italian foundations like “Nord-Est”³ who with the project “FabLab a scuola”⁴ has realized FabLabs in eleven schools in the north east of Italy. However, southern schools are not participating in these kinds of initiatives.

Sicily hosts six FabLabs with either educational or commercial purpose. These FabLabs are located in different cities of Sicily: Agrigento, Catania, Messina, Marsala, and two in Palermo. These are all spaces equipped with high-tech machinery, tools and design software, open to the local community. In some of the FabLabs, there is a strong link with the local schools, whereas in other cases the focus lies more on sharing the space, technologies and machines with the public.

In Palermo, there are two FabLabs: “FabLabPalermo” (https://fablabpalermo.org/) and “FabLab@School”. The first one is a commercial FabLab for public use, whereas the latter is a mini-FabLab located within the Vittorio Emanuele High School. However, the use of this FabLab is not limited to the school who hosts it, but offers also the possibility for other schools to use it. Besides schools, also individuals and organizations can use the FabLab in order to sustain itself after the national funding ended. FabLab@School is the first FabLab located in a school in southern Italy⁵ however, despite how the name would suggest, it is not a part of the fablab@school movement initiated by Stanford University. Within the context of the FabLab Schools EU project, two schools participated using the facilities offered by the FabLab@School space. The first one is the Liceo Artistico Statale Vincenzo Ragusa e Otama Kiyohara, an artistic high school. The other school is the Instituto Tecnico Industriale Vittorio Emanuele III, a technical high school. From these schools a total of six teachers participated in the project: two teachers from the Vittorio Emanuele III school, and four from the Ragusa – Kiyohara school. These teachers come from a range of different disciplines such as Italian, English, architecture, informatica and geometry, and used this project to discover new ways of teaching and learning.

For the CSC Danilo Dolci, the participation in the FabLab Schools EU project and the sharing of experiences and skills on an international level is very important. The adoption of the FabLab technology and thinking as part of the education programme, as it has been shown in Denmark or in the Netherlands does not yet exist in Sicily, but it has a huge impact on the development of students’ and the teachers’ competences. The approach promoted by FabLab Schools EU and the design circle developed by Aarhus University are deeply different from what is currently happening in Italian schools; nevertheless it is seen by CSC as a necessary step towards teaching and learning in new ways in a digitalised society, following the path already shown by the European policies.
Teachers in Spain, Italy, The Netherlands and Denmark have worked for two years to integrate new teaching practices related to digital fabrication in concrete learning environments. They have been developing students’ and teachers’ skills to engage with authentic design problems, critical design with and reflection on technology. These skills ultimately empower students to make more informed decisions about technology in their lives and empower them to take active part in developing our future digitalized society.

The project has developed three main results:

- A set of methodological principles for educational digital fabrication in school.
- A manual on educational digital fabrication targeted at teachers.
- Policy recommendations on how to adapt a FabLab approach

This manual is one of the main outcomes of the FabLab Schools EU project. It describes the tested approach, methodology and principles to design thinking and digital fabrication in education.

Secondly, it provides a set of inspirational projects, which were developed by the participating teachers over the course of the project. The manual is also an outcome of a two-year process in which teachers from the different countries have participated in workshops and explored new methods and experiences within their own classrooms. Through a facilitated process of exploration, in-practice training experiences, twinning and constant evaluation done by Aarhus University, the methodological principles and teacher projects presented in this manual have been developed.

The manual is thus directed at teachers, but not only. Due to the growing importance of digital fabrication for students in schools, the manual also serves as a recommendation for policy makers on different levels, for improving the education system at school or in their region.

«Quotes and vinyl cut» project.

«House of words» project.
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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.

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**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
A Design Based Approach to Digital Fabrication

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.
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 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).

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

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

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 resources 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?

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?
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.
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.

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.
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 ones 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.

Focus of the phase:
- 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 that 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.

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.
- Students have to use insights and ideas from field analysis that are not necessarily their own personal ideas and wishes.

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.

Pedagogical principles:
- 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.
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 to convey their presentation in a language so that everyone retains interest.

It is a 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.

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.

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.
«Tinguely» project.

«Sustainable school» project.
Getting Started with Teaching Design Thinking and Digital Fabrication

Getting started sounds easy, just do it. But taking the first step in doing something new or putting theory into practice is more difficult than one would expect. There are always countless reasons why not to get started. This section is here to help you to take that first step. All teachers involved in the project have been designing new projects to learn, explore and evaluate the approach and methodology described in the previous two chapters. 15 selected projects are included in this manual, additional projects can be found on the FabLab Schools EU website (http://fablabproject.eu/manual). The projects deal with a broad array of school subjects ranging from language to arts, geography to technology. Each project is presented as a summary containing a short introduction followed by a table with practical information about the intended age group, time needed and course subject. The short descriptions should enable you to choose which project fits your needs and ideas, and hereby which project to start with. A link provides you access to additional information on your chosen project, such as lesson plans, equipment needed and expected challenges and learning goals. This additional information is only available in English.

The summaries are meant to get you started with teaching digital fabrication and design thinking. Each of these projects will allow for customization and personalization. Indeed, your local context and materials available will differ from those described in this manual. We challenge you to get inspired, improvise, and adapt these projects and hopefully share your experiences with your teaching community.

Now it is time to get started.
«Sustainable house» project.
A Robotic Insect

In this project students create a robotic insect that reflects their abilities. During the design brief phase the students explore their skills, sports, hobbies, etc. Investigation of existing robots and insects is part of the field study phase. After the ideation phase prefabricated materials combined with laser cutting and 3D printing will be used to make a fantasy insect. An important requirement of this robot insect is that it can actually move by means of a motor. At the end of these lessons the students have to present the robot. They tell their fellow students about what they have done, why they have chosen specific forms in relation to their abilities and hobbies as well as how they collaborated throughout the process.

Tip from an expert/pedagogical principle:
“Stimulate working in mixed groups, boys and girls together.”
“When the group exceeds more than 25 students use peer experts in 3D printing, computer science and the laser cutter.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>25-30 lessons of 50 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>10-13 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Technology &amp; Design</td>
</tr>
<tr>
<td>Additional resources:</td>
<td><a href="https://goo.gl/Rf5vEb">https://goo.gl/Rf5vEb</a></td>
</tr>
</tbody>
</table>
Awareness Factory 2

In this project, students are stimulated to think about the cause of environmental problems, and the challenges related to sustainability. They will have the chance to express and visualize their ideas and insights to the outside world through different, self-chosen mediums. Students research the different ways of visual expression and design their ideas. For the design and production, students can use the software Inkscape, a laser cutter, vinyl cutter, and a plotter. The main objective is the production of attractive, original and aesthetic visual means of exhibition, capable of transmitting information without text to support alternative reflections. Within this specific project, one means of representation is based on traditional values of Kamishibai-Butai, a “paper theater”, while another was based on a more modern mean, of stickers.

Tip from an expert/pedagogical principle:
“Teamwork. To draw the scenes of the kamishibai as a group, the aesthetic continuity of the work developed by the different students is more important than the artistic quality of the final product.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>25 lessons of 1 hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>12 – 16 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Arts, Literature, 3D Design</td>
</tr>
</tbody>
</table>
Learning by Playing

This project makes students aware about what things they find challenging in the Danish language, it’s also applicable in other contexts.

The way the students work with this is by inventing their own board game. There are demands towards the design, were they have to use technologies like 3D print and laser cutter. Besides getting knowledge in what they find challenging in the language, the students will be working with transforming ideas on paper into tangible objects like the pieces for the game, and also the actual board itself. They have to use software to shape their ideas, and gain knowledge about the materials they use in the different machines.

All of this is only possible, if the group can agree on making compromises and join their innovative skills into one idea about how to play the game. Among other things, they have to examine different board games to learn how different the game play can be, this will take place in what’s called the field study. Later on in the process they will be forced to get a lot of ideas about how to play the game in different ways, so the group have original ideas to build their own game on.

They then have to turn their ideas into tangible objects with digital technology.

Tip from an expert/pedagogical principle: “I found that giving the students time to examine different games gives them better chances to get new ideas on how to play the game.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>17 lessons of 45 minutes</th>
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<tr>
<td>Age group:</td>
<td>11-16 years old</td>
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<tr>
<td>Course subject:</td>
<td>Danish, crafts and design, math</td>
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<tr>
<td>Additional resources:</td>
<td>Powerpoint: <a href="https://goo.gl/SG4U8p">https://goo.gl/SG4U8p</a></td>
</tr>
</tbody>
</table>
Working Towards Sustainable Development

The topic of this project is the transition towards sustainable development. Starting from the concept of sustainable development, the project aims to create an artefact through the use of recycled materials. During the initial research phase on the central theme of “sustainability” and the possible transition from unsustainable development to sustainable, students will explore and analyze various solutions that involve low energy consumption, water saving, recycling, renewable energies, environmental cleaning, sustainable mobility. This will increase the students’ knowledge about waste disposal cycle and recycling of materials. After exploring together with the students what could be daily practices that can help keep the environment clean, students design prototypes from recycled materials (paper, cardboard, plastic, cans, etc.), and with a focus on sustainability. In small groups, students will go through a field study phase after which they design various models, and eventually propose a prototype. In our activity, for example, the students designed a drink dispenser made of cardboard and plastic bottles.

Tips from an expert/pedagogical principles

- Involve students through the use of multimedia material (audio, video, photos, etc.).
- Leave space for students’ creativity and adequately discuss their ideas.

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>12 lessons of 1 hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>15 – 17 years old</td>
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<tr>
<td>Course subject:</td>
<td>Technology and design; ICT.</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>Teachers’ blog on the process: <a href="https://syd2015.wordpress.com">https://syd2015.wordpress.com</a></td>
</tr>
</tbody>
</table>
Increasing sustainability at school with our school garden

The project is about improving a school garden or establishing a new space as a school garden, in order to show students the importance of creating a more sustainable society. The students will imagine and design different parts of the new garden, for example some window boxes to hang on the school fence in order to create a vertical garden, or a greenhouse to grow plants in bad weather conditions. Along the way, the students will learn about the properties of different materials to use in the garden, how to apply eco-friendly methods to the garden and how to make designs for digital fabrications using Inkscape and a laser cutter.

Tip from an expert/pedagogical principle: “The main goal of the project is to foster collaborative work and improving student’s skills when making decisions.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>12 lessons of 50 minutes @school 5 lessons of 4 hours @FabLab</th>
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</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>8-9 years old</td>
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<tr>
<td>Course subject:</td>
<td>Arts, Science and English</td>
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<tr>
<td>Additional resources:</td>
<td>Pictures of the project: <a href="https://goo.gl/fe9wQ9">https://goo.gl/fe9wQ9</a></td>
</tr>
</tbody>
</table>
In this project, students will learn to convey words and emotions by architecture through first studying the creative methods of great masters and then reverse the process: starting with chosen words as the basis of an architectural design. Students will start with a study of the designs of architectural masters, which words and emotions their architecture transmits, and how they do that. The students have to write down ten words which describe an architectural design of an architectural master. The field study phase consists of iconographic research on the type of architecture and on materials related to the words students identified from the design. After the research, students can choose two of the ten words to design their own house. In the ideation phase, the students will make preliminary sketches about the forms, distribution, volumes and physical materials that are intended to be used in the project. The sketches will be developed further during the fabrication phase through digital modeling with the SW Rhino 3D software and digital models can be printed with a 3D printer. In the end, students will make an integral architectural design, inspired by emotions in order to learn how to go from emotions and words to an architectural design.

Tip from an expert/pedagogical principle: “It was very useful to use sharing, argumentation and reflection in each phase of the project, not only at the end.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
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<tr>
<td>Age group:</td>
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<td>Course subject:</td>
<td>Architectural design</td>
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<td>Additional resources:</td>
<td>Video: <a href="https://goo.gl/JYyBKx">https://goo.gl/JYyBKx</a></td>
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<td></td>
<td>Pictures of the process:</td>
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<td></td>
<td><a href="https://goo.gl/BDWt4A">https://goo.gl/BDWt4A</a></td>
</tr>
</tbody>
</table>
Enhancing the value of a monument

This project will develop students technical skills and teach them more about the city they live in. The students will study (undervalued) monuments in the city and make artefacts that help to increase the value and appreciation of the monument by replicating their shapes or use it as inspiration to develop different kinds of materials that can increase its appreciation.

It is important for students to “know” the city in which they live and its artistic, architectural and cultural heritage. Furthermore, it is a great challenge to discover how to value areas whose beauty is not recognized. The students will follow the phases of the design circle: they will explore their city and, in pairs, they will develop their ideas from a stream of personal suggestions, from interviews with tourists and inhabitants and from observation of the sites. The physical product of their work will be 2D graphics (a tower shaped brochure for example), 3D Cad models, jewellery and gadgets, authentic expression of an undervalued site and the rewarding result of interactive design and fruitful teamwork. The methods used will be industrial, artisan, digital, or mixed.

Tip from an expert/pedagogical principle:
“Students must continually check if they are fulfilling the aim, being conscious that they may need to change their ideas along the process.”

| Time/amount of lessons: | 30 lessons of 55 minutes |
| Age group: | 15 – 16 years old |
| Course subject: | Italian, English, Design and CAD Lab. |
| Additional resources: | Presentation of the project: https://tinyurl.com/ycfvgdb9 |
Me, myself and I

Me, myself and I is a collaborative project between the subjects Arts and Technology. In this project, the students are challenged to think about the question: Who am I? and create a 3D expression of themselves. During the design brief phase, the students will have to discover who they are, what is important to them, what they like, etc. A tool used to explore this is the mind map. In the field study students gain theoretical knowledge about a number of art movements and develop digital fabrication skills. Emphasis in the ideation phase is on divergent and creative thinking. Through a couple of cycles the students will improve their idea. The design outcome of this project is an original personal sculpture, using clay and the laser cutter. Learning goals of this project involve gaining technical skills, learning about art movements, personal growth and discovering who you are.

Tip from an expert/pedagogical principle:
“The main goal of this assignment is to teach divergent and creative thinking. The assignment provides several field studies the teacher can choose from.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
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<tbody>
<tr>
<td>Age group:</td>
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<td>Course subject:</td>
<td>Italian, English, Design and CAD Lab.</td>
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<tr>
<td>Additional resources:</td>
<td>Presentation of the project: <a href="https://goo.gl/gs6eAd">https://goo.gl/gs6eAd</a></td>
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</tbody>
</table>
Our Sustainable School

In this project, students will initiate the change towards a more sustainable school by designing sustainable furniture or re-use and redesign old furniture. During the Field study, students will acquire the knowledge of the great masters in architecture and their use of sustainable design and materials. Furthermore, students will do real field work in the school in order to map the spaces of the school to which students could add something, to see the positive sites that could be enhances, and to interview students and staff about the needs they have in the school. This need based analysis will give the direction to the project. Through brainstorm and exchange of ideas, fabrication can either involve a digital project of spaces using specific software, or the actual fabrication of furniture in a FabLab.

With this project, students will understand the meaning of sustainability by applying it to a concrete and familiar environment (the school). Furthermore, students will learn the different techniques of architectural design, CAD, 2D and 3D digital modelling, and the different traditional and digital fabrication techniques of models and prototypes.

Tip from an expert/pedagogical principle:
“Growth is achieved by challenge and confrontation.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>7 lessons, total of 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>15 – 18 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Architecture</td>
</tr>
</tbody>
</table>
Motivate to read - Redesign the library

The students will learn to “read” a room (the library) and its functions, as well as creating alternative ideas. The project aims to help discover and define a problem, and through a scaffold design process, to come up with their own version of a well-argued solution. After a field study at the school library and an ideation phase, the students will create a new way to look at and use the library. You can either make the products that are presented in the project, or you can take your students through the whole process and see what designs and ideas your students will come up with.

Tip from an expert/pedagogical principle: “The course can be scaled. If you choose to create the same products as we did, your field study and ideation will be about finding the right icons for the right books. This will be a short version. In the full scale - allow the students to come up with their own ideas to a solution of the problem.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>18 lessons of 45 minutes</th>
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<tbody>
<tr>
<td>Age group:</td>
<td>10-11 years old</td>
</tr>
<tr>
<td>(will work with older students as well)</td>
<td></td>
</tr>
<tr>
<td>Course subject:</td>
<td>Art, Craft and Design, language</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>Presentation for the whole course inspiration on the blog: <a href="https://goo.gl/rVG6eG">https://goo.gl/rVG6eG</a></td>
</tr>
</tbody>
</table>
The mission of this project is to inspire children to read, to keep on reading and to read even more. To achieve this mission, students will use words and text to decorate a room (in this case a Pedagogical Learning Centre). In this project the students will work through all the phases of the Design Circle. The teaching material should be regarded as a didactic template that can be used in the development of design and digital fabrication processes. The template can be used in all contexts where you want to make signs, stickers, manufacture of t-shirts, etc.

Tip from an expert/pedagogical principle:
“The main digital fabrication used in this project is the vinyl cutter. It works best if the students know how to work with the vinyl cutter and the software that comes with it in advance. But the students can also learn along the way with small training project on the side.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>21 lessons of 45 minutes</th>
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<tbody>
<tr>
<td>Age group</td>
<td>11-12 years old</td>
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<tr>
<td>Course subject:</td>
<td>Handicrafts and design, Danish</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>Videos: <a href="https://www.youtube.com/watch?v=9zvVP88KbdU&amp;t=9s">https://www.youtube.com/watch?v=9zvVP88KbdU&amp;t=9s</a> <a href="https://www.youtube.com/watch?v=YM">https://www.youtube.com/watch?v=YM</a> SeuxcGwk <a href="https://www.youtube.com/watch?v=baQGefhFN2I&amp;t=7s">https://www.youtube.com/watch?v=baQGefhFN2I&amp;t=7s</a></td>
</tr>
</tbody>
</table>
Recycling Game: 
Where do you throw it away?

In this project, the students will design and fabricate a board game with which they will easily learn to identify the type of waste that goes in each container. The objective is to design a game that teaches how to recycle by playing, therefore raising awareness on environmental issues.

The students will work in groups and follow the phases of the Design Circle. In the ideation phase they will consider different possible solutions for a game and make some sketches. Students will have to agree on one design that will be manufactured in the fabrication phase. Using a laser cutter, vinyl cutter and 3D printer the different part of the game can be executed. In the end the students will also elaborate the game’s instructions.

Tip from an expert/pedagogical principle: “All team members should feel free to express their ideas, no matter how unusual.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>26 lessons of 55 minutes</th>
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</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>12-16 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Biology and English</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>pictures of the project process: <a href="https://goo.gl/R957wH">https://goo.gl/R957wH</a></td>
</tr>
</tbody>
</table>
**Sustainable Andolina**

This project emerges as a way of working with the Sustainable Development Goals of the United Nations. Specifically, goal 11 “Sustainable cities and communities”. The aim of the project is to design and manufacture «something» that would help in the school of the students.

The starting point is to think in groups about the definition of sustainability. Students will think about questions such as: How can we make our city more sustainable? And what about our school? By the use of images, students will debate and put their ideas together. The design has to meet three requirements: ecological, stackable and easy to clean materials. The designs can be manufactured during the fabrication phase; however, it is good to keep in mind what are realistic projects. In this particular project, students decided to manufacture containers to facilitate the separation of waste within the centre. The students follow all the phases of the Design Circle and learn and use digital design and manufacturing tools.

Tip from an expert/pedagogical principle:
“Starting from personal experiences and then deepening them is an essential key to the genuine interest of students.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>10 lessons of 30 minutes @school</th>
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<tr>
<td></td>
<td>4 lessons of 3.5 hours @FabLab</td>
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<tr>
<td>Age group:</td>
<td>9-12 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Crafts, Geography and History</td>
</tr>
</tbody>
</table>
The Sustainable City

The city in transition: from unsustainable to sustainable.

This project is about designing objects in public (green) spaces to create a (more) sustainable city. The objects designed should not only be made of sustainable materials, but also contribute to a growing awareness and education on sustainability in the city.

The project starts with the theme of “overpopulation and the unlivable condition of the city”. The field study will consist of self-reflection, interviews in the street with tourists and locals on the pros and cons of the city, and a review of chosen literature. The students will reflect on what does not work in today’s world and why. In order to have different opinions and alternative solutions that might not be shared by the economic market, the students will read extra literature, such as the book “Invisible cities” from Italo Calvino, watch selected documentaries and will have a debate in order to stimulate their interests and motivate their choices. This coincides with a research carried out at the same time on sustainable and recycled materials. The main question then follows for the students: “How can you contribute?” During the ideation phase different ideas will be put forward, shared and chosen, which in turn will be executed as prototypes during the fabrication phase, leading to a scale-model of a park.

Tip from an expert/pedagogical principle:
“Use the literature to reflect and learn new things, to gain a deeper understanding of the topic. This will then be the starting point from which students can continue ideation and fabrication. However, the phase of getting informed on different opinions and ideas is as important as the actual fabrication of the prototype.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>21 hours (divided over 6 lessons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>15 – 16 years old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Italian, Geo-history, Design and planning</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>The book “Le Città Invisibili” by Italo Calvino</td>
</tr>
</tbody>
</table>
Project Tinguely: 
Art that moves you

This project is about kinetic art. The students design a kinetic sculpture that fits into an existing location. Along the way the students learn about the mechanics of making things move and how to make designs for digital fabrication. The students work in pairs and follow the phases of the Design Circle. The kick-off of the project is a presentation on kinetic art and the work of the Swiss painter and sculptor Jean Tinguely. During the field study the students will go out and explore the context in which the sculpture should be placed. The ideation phase will be multiple cycles of diverging and converging ideas. A lengthy fabrication follows the ideation to build a working prototype of the kinetic sculpture.

Tip from an expert/pedagogical principle: 
“it is more important that students come up with multiple different ideas than making beautiful drawings.”

<table>
<thead>
<tr>
<th>Time/amount of lessons:</th>
<th>26 lessons of 50 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group:</td>
<td>14 – 16-years-old</td>
</tr>
<tr>
<td>Course subject:</td>
<td>Technology &amp; Design</td>
</tr>
<tr>
<td>Additional resources:</td>
<td>Presentation: <a href="https://tinyurl.com/y7k45yh5">https://tinyurl.com/y7k45yh5</a></td>
</tr>
</tbody>
</table>
Many digital fabrication workspaces are inspired by the Fab-Lab vision of MIT media lab (https://www.media.mit.edu/projects/fab-labs). The idea behind these laboratories is that they empower the general public “to conceptualize, design, develop, fabricate, and test almost anything” by making open-source digital fabrication and electronic tools accessible locally.

Officially licenced Fab labs can nowadays be found around the globe. Founding a licenced Fab lab can be a costly business but is luckily not necessary for a school to start teaching digital fabrication.

This section will give a brief overview of three types of tools which we think are essential for a digital fabrication workspace at school. Ideally the workspace should also include hand tools like, drills, saws, pliers, screwdrivers, etc. In addition to these crafting tools, a workbench for electronics with soldering stations, power supplies, oscilloscope, etc. is a must. To enhance student’s projects with light, sounds, movement or interaction a growing list of easily programmable microcomputers, like Arduino (http://www.arduino.cc), MakeyMakey (http://www.makeymakey.com), Micro:bit (http://www.microbit.org) and Littlebits (http://www.littlebits.com) can be a further addition to the inventory of the workspace.
3D printing is a fabrication process which transforms a digital 3D design into a physical object. Much like a regular printer for text, a 3D printer uses a moving head to precisely "drop" material on a specific place. The most common desktop 3D printers use a type of plastic as material. The printhead is heated to melt the plastic. Each layer is stacked upon each other.

How does 3D printing work?
The first thing you need to start 3D printing, besides a printer, is a digitally designed object. There are many resources on the internet to download a suitable 3D model, such as thingiverse (https://www.thingiverse.com) or all3dp (https://www.all3dp.com). It is also possible to design a 3D model yourself.

A widely used popular program for creating a 3D model for printing is Thinkercad (https://www.thinkercad.com) from Autodesk. This is a free online platform which does not require a steep learning curve. Rhinoceros has been developed from a designer/artist point of view which makes it more intuitive to use, whereas Solidworks is mainly used by engineers. Both programs are quite expensive. Fusion360 is from the same organization as Thinkercad but has more options. As a bonus, it is free for educational purpose. The next step in the process of 3D printing is slicing the model. Using a special program, the 3D CAD file is sliced in thin layers and converted to a string of codes which tells the printer where to move to and how much material should be dropped. Two widely used slicing programs are Simplify3D and Cura.

Both programs take an .stl (SurfaceTessellationLanguage) file as input. All of the above-mentioned programs can output the 3D designed object as .stl file. It is important that the printer setting in the slicing program matches the 3D printer.

3D printing in the classroom
For a great experience in 3D printing in the context of education there are many things to take into consideration. As with many things, in general the more expensive the better the quality. Secondly, the atmosphere in the classroom is important. Preferably, the air around a 3D printer is ventilated, after all you are melting plastic. Also, the air in the classroom should not be too humid because this affects the quality of the printing plastic (filament). Thirdly, the quality of the filament. Again, the more expensive filament proves to be better. Not only is the quality of the print better, it is also more consistent in composition and, therefore, does not lead to clogging the printing head too much. It is highly recommended to use eco-friendly materials, such as PLA. This is a bioplastic derived from renewable materials such as corn, sugarcane, or tapioca. PLA is, unlike other plastics, not based on petroleum and requires less energy to produce. It also releases fewer irritating fumes than other plastics while working with the 3D printer.

To save money it is also possible to make it a project for students to build a 3D printer.
Laser cutting

Laser cutting is a fabrication process which uses a focused high-powered laser beam to precisely remove a small portion of material. The laser beam can cut through a material (cutting) or just scrape the surface of a material (engraving).

How does laser cutting work?
The first thing you need for laser cutting is a CAD vector file. CAD (Computer Aided Design) Vector files are prepared in software like Adobe Illustrator, Inkscape or Autodesk fusion360. Illustrator is part of a larger expensive digital design suite including Photoshop and InDesign. When you are familiar with any of the programs in the suite, it is relatively easy to learn the others. Inkscape is a free vector drawing program. The main benefit of Autodesk fusion360 is that it can also be used for creating 3D models. In addition, Autodesk has a free application which turns 3D models in vector slices for laser cutting.

After the file is sent to the laser cutter, a laser beam is emitted from a laser tube and passed through mirrors to point the beam through a fixed-focus lens in the machine head. The lens focuses the beam onto a point on the surface of a flat sheet material, melting, vaporising or burning the material at that point and moving along the cutting line as dictated in the vector file that the machine has been provided with. This melting and vaporisation of the material, especially with plastics, leaves a melted, almost polished edge, requiring little to no finishing, depending on the final purpose. A focused cutting beam means that the ‘kerf’ (the amount of material removed by the laser) is very little in comparison to a blade or cutting edge. This does vary from material to material and depends on the thickness. This also allows tight nesting of laser cut parts to reduce waste and make the most of your material.

The speed and thickness of the cutting process depends on both the power and the path length of the laser beam.

Laser cutting in the classroom
The biggest advantage of a laser cutter as a digital fabrication tool is the speed with which it works. When buying a laser cutter, there are two important parameters to consider: power and bed-size. It is not necessarily true that the more power (watt) of the laser tube equals higher cutting depth or speed. The cheaper machines have an open tube and lesser quality optics resulting in power loss, where the more expensive machines can cut to the same depth with a lower power laser tube. When it comes to bed-size, a benefit of a larger bed is the possibility of cutting multiple students works in one go, making the workflow faster. Besides the machine you also need a heavy-duty air ventilation system and compressed air.

A laser cutter is a great tool for digital fabrication in education but working with a laser comes with safety precautions. When working with young students, it is best to have an adult supervising the laser cutting.
Vinyl cutting

Vinyl cutting is a production process that uses a computer-controlled blade to cut shapes and letters from thin sheets of vinyl.

How does vinyl cutting work?
The input file required by a vinyl cutter is usually a vector file. Just as designing for the laser cutter, these vector files can be designed in several software suits, both paid and free of charge. To cut the designed shape, the blade of the vinyl cutter precisely follows the vector path by moving in the x and y direction. Vinyl typically comes on large rolls thus allowing for long designs like banners. A limitation of the vinyl cutter is that each roll of material is of one solid color. To make a multicolored design each specific color needs to be designed and cut from a separate roll of material and then put together.

Besides plain solid colors the adhesive vinyl nowadays also comes in a wide variety of colors and materials including gold and silver foil, vinyl that resembles frosted glass, holographic vinyl, reflective vinyl, thermal transfer material, and even clear vinyl imbedded with gold leaf.

Vinyl cutting in the classroom
Out of all the FabLab equipment the vinyl cutter is the cheapest (around 500 euro) and easiest to setup (plug and play). Most smaller desktop vinyl cutters can be used without special software for designing custom shapes and letters. The small desktop vinyl cutters (e.g. Brother’s ScanNCut) include software and an online platform that allows you to make your own design. This is often easier than using a vector program as described above. They also give you the opportunity to scan an image and use this as input for the vinyl cutter. Next to cutting self-adhesive vinyl, other thin-sheet materials can be used, such as paper and fabric. In addition, in several vinyl cutters the blade can be replaced by a (fabric)marker to produce drawings.
«Tinguely» project.
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Mads Bo-Kristensen: madbo@vejle.dk

Aarhus University, Denmark
http://www.au.dk/
Rachel Charlotte Smith: rsmith@cavi.au.dk

LABoral Centro de Arte y Creación Industrial, Spain
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Lucía García Rodríguez: lucia@laboralcentrodearte.org
Karin Ohlenschläger: karin@laboralcentrodearte.org

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