Teaching in open learning environments

Challenges and opportunities

Generic 21st century skills

In chapter 1, we interviewed 11 STEM-professionals working in different sectors all over Europe. Across the interviews, it became clear that there are several crucial competences for STEM-professionals. These are not only specific STEM-related competences (such as content knowledge and application of science, technology, engineering and mathematics), but also more generic competences. These generic competences can also be described as 21st century competences. The interviewed professionals referred to them as 'willingness to learn, problem solving skills, creativity, ability to communicate, being pro-active, sense of entrepreneurship, being able to work in group, and flexibility'. Also in the scientific literature, similar listings of transversal skills (such as critical thinking, collaboration and problem solving) are described *(e.g. Bell 2010; Davies, Fidler & Gorbis 2011, Jang, 2016)*.

In the current chapter, we summarize them by using five 'umbrella concepts':

- Problem solving
- Creativity
- Critical thinking
- Group work
- Entrepreneurship

Problem solving

Problem solving includes identifying the problem, generating a set possible interventions to achieve the end goal, evaluating the best solutions, implementing a plan and assessing the effectiveness of the plan. This sequence can be repeated if the solution is not sufficient, which makes it a problem solving cycle.

Creativity

Creativity is the capability to generate new ideas and turn them into reality. Creativity also plays a role in successful problem solving, as this requires the ability to generate a set of alternative interventions. New solutions, new ways to perceive the world and seeing patterns and connections that are less obvious, are all manifestations of creativity.

Critical thinking

Critical thinking is the ability to reflect on the truthfulness of claims and to think rationally about what to do and to believe. People who think critically make reasoned judgements and base their conclusions on well-thought and logical arguments. It also involves the capacity to reflect on its own thinking and acting, implementing a metacognitive perspective.

Group work

Group work is a form of learning in which students engage with other students. Rather than exclusively exploring the learning concepts individually, students learn together and from each other. Besides learning to successfully managing a small project, students also learn to communicate effectively. Especially if the result from a group work (e.g. gained knowledge, the result from a design process,…) is shared with other groups. Also other social skills, such as co-operating, resolving conflict, group decision making and adopting a variety of group roles, are learned through group work. Students learn to be courteous to others, to share materials, to listen carefully to others, compromising, accept responsibility and understand what behavior is appropriate in a given situation and thus act accordingly.

Entrepreneurship

Entrepreneurship can be considered as a sense of initiative, and the ability to turn ideas into innovations. Also, it allows students to learn more than just their own field of study, as the innovation is embedded within the outside world. Successful entrepreneurship pays attention to production efficiency, sustainability, and the created value for others. Students who are encouraged to be enterprising, also learn to improve organization skills and time management.

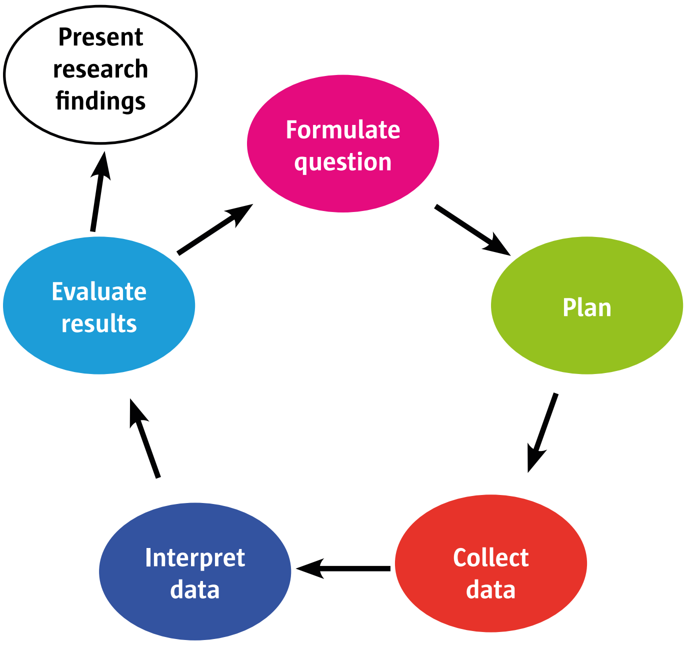
Note that the concepts described above are often interrelated (e.g. you need some creativity for successful problem solving), and that one skill can be employed to improve another skill (e.g. group work can be an effective method to stimulate critical thinking, by discussing claims and strategies).

Research and design cycle

STEM professionals are often confronted with research and design challenges. For instance, a biochemist of a bio databank of pathological tissues has to think along with researchers who are investigating cancers, or with the doctors who are examining the tissue of a patient. An electrician is challenged with broken electrical systems or with the need for a new solution, which in turn requires to go through a design cycle.

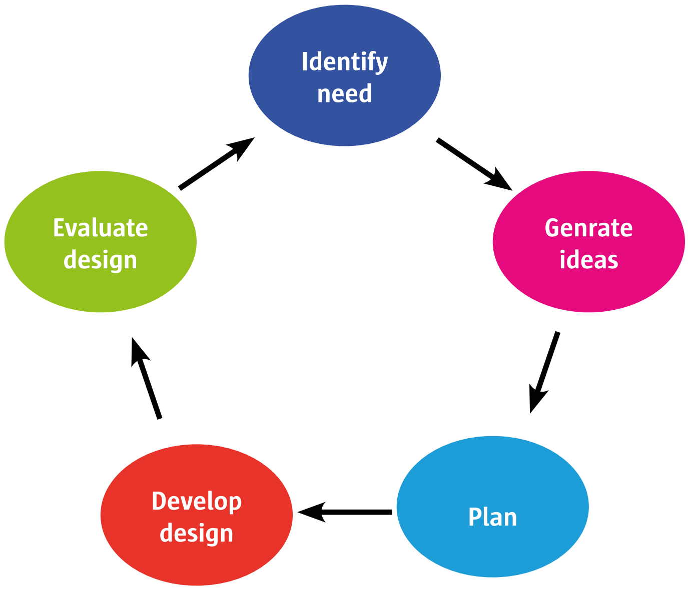
A research cycle typically follows these steps:

1. **Formulate question**: identify the desired knowledge and specify the research question.
2. **Plan**: make a plan to collect your data. Decide what you need (e.g. materials), how will you gain information (e.g. experiment) and how will you capture the information (e.g. data file).
3. **Collect data**: carry out all the steps of your data collection plan.
4. **Interpret data**: sort and organize your data and analyze the results. Describe your conclusions.
5. **Evaluate results**: assess whether the conclusions of your interpretation solve the research question or provide you with the desired knowledge. If there are any questions remaining, reiterate the research cycle.
6. **Present research findings**: share your findings with others.



A design cycle consists of the following steps:

1. **Identify need**: describe the problem and identify the need precisely.
2. **Generate ideas**: formulate different solutions and choose the most suitable one.
3. **Plan**: make a design plan. Decide what materials you need and which design steps you need to follow. Consider which potential problems can be foreseen.
4. **Develop design**: create, build, program, develop,… design artifacts and processes.
5. **Evaluate design**: examine if the design works properly and if the design caters to the needs. Reiterate the design cycle and adapt the design if necessary.



Going through a research and design cycle, is an excellent opportunity to stimulate 21st century competences in students. For example, the interpretation of data in the research cycle stimulates critical thinking and the idea generation step in the design cycle requires creativity. Of course, these are only a few examples in a range of possibilities. Both cycles are also a good example of problem solving strategies.

Challenging students with research and design problems, allows to go through the research and design cycles and consequently forms the ideal breeding ground to develop 21st century competences.

Prepare students for the future

To be sure that the future generation of STEM professionals is well prepared for the challenges in the workplace, it is important that both specific STEM competences and generic competences are developed (OECD, 2018).

According to a report from the European Union (2015), STEM competences are essential for the 21st century and more attention should be paid to skills that are not easily acquired through traditional teaching. With traditional teaching, we refer to the concept of one teacher in front of a classroom, providing students with information. In the Artifex project, we aim to help teachers to stimulate the 21st century skills in students.

By providing students with research and design challenges, teachers can stimulate students' 21st century competences. More precisely, teachers can foster these generic competences in the following way:

- **Problem solving**: teachers can stimulate students to effectively go through the problem solving cycle. As research and design cycles are excellent examples of problem solving cycles, guiding students through the associated steps, and explicitly mentioning these steps, helps them to successfully adopt a problem solving strategy.
- **Creativity**: students can be encouraged to be creative by giving them the opportunity to experiment, explore and use their imagination. Allow students to go off the beaten path and make clear that there are no 'bad ideas' to encourage students to express their ideas.
- **Critical thinking**: teachers can provide students with intellectual challenges to stimulate critical thinking. Students can be encouraged to look into the truthfulness of claims, to search for reliable sources and to reflect on their own decision making process.
- **Group work**: teachers can actively search for opportunities to let students learn in a collaborative way. Group tasks, debates and explaining concepts to other students are some examples of learning activities that encourage students to work together and learn from each other.
- **Entrepreneurship**: teachers can encourage students to be enterprising by giving them the freedom to explore and to fail and by letting students reflect on the created value of their idea. Autonomy allows students to be regulate their own organization skills and gives room to experiment with different strategies.

High-tech informal-learning environments

Stimulating students' 21st century skills by letting them go through research and design cycles, can generally be done in any environment. However, some environments provide extra opportunities to maximize the growth in the learning curve. Educational contexts optimally suited for exploration and development of generic skills are informal learning environments (Schwarz & Stolow, 2006). Informal learning environments (also called open learning environments) are characterized by their accessibility for the larger community. The spaces are open for every learner, and knowledge and tools are shared. These environments provide compared to traditional classrooms more room for exploration and are typically student-centered with a focus on problem-based active learning *(Bell, 2010)*. Examples of informal learning environments are Fablabs, libraries, museums, science centers, nature reserves, etc.

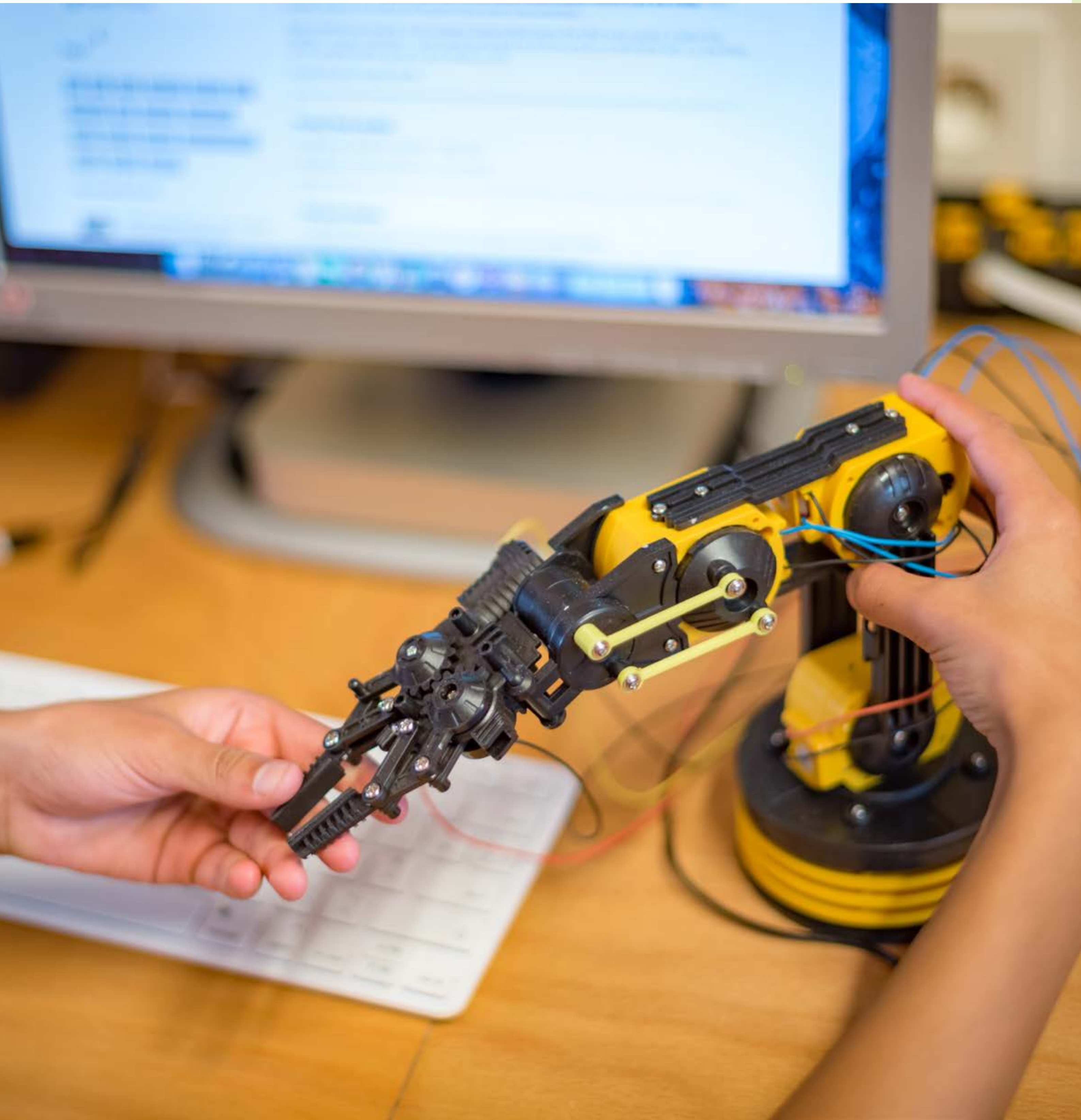
When it comes to STEM competences (both specific and generic), informal learning environments with the presence of high-tech manufacturing equipment are particularly beneficial for students' learning. These spaces are interchangeably referred to as Fablabs, Makerspaces, Hackerspaces, Robospaces, etc. These high-tech informal learning environments can be characterized as community workshops where citizens share access to tools that allow them to (co)create products and processes. Students, but also the larger learning community, can come together to create, invent, think, explore and discover a variety of high-tech tools and materials, such as 3D printers, laser cutters, and similar equipment. High-tech informal learning environments have the potential to develop teaching, learning and coaching that can foster interests in STEM and stimulate the development of STEM-specific skills and 21st century skills *(Boaler, 1999; Geier et al., 2008; Vuorikari, Ferrari & Punie, 2019)*.

Fablabs and informal learning environments in general do not only provide students with a lot of learning opportunities, they are also suited to challenge teachers in the development of their competences. Improving both students' specific STEM-related knowledge and skills and students' 21st century skills in a non-traditional learning environment, requires teachers to feel sufficiently prepared to coach, teach and learn in a high-tech open learning environment.

Teaching in a high-tech informal learning environment: the Artifex research

Within the Artifex project, we investigated the degree in which teachers feel prepared for teaching in a high-tech informal learning environment. In a collaboration between the University of Antwerp and the University of Karlstad, Belgian and Swedish teachers were asked about their feelings of competence, and their concerns regarding working in a high-tech informal learning environment.

The results of this educational research provided insight in the current state of affairs with regard to STEM learning in informal learning environments, and they contributed to the development of the Artifex workshops. In the following section, we provide information about the conclusions of the Artifex research and we subsequently expand on the experiences from teachers who tested the Artifex workshops.



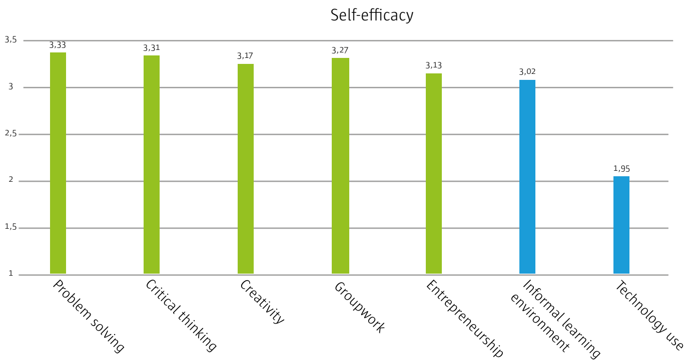
Challenges for teachers in open learning environments

The degree in which teachers believe that they are capable to guide students through their learning process, is also referred to as 'self-efficacy'. Self-efficacy is a concept that has been defined by Bandura (1993) as a person's belief in his/her ability to succeed in a particular situation. With regard to teachers' self-efficacy, Bandura stated that it is about teachers' beliefs in how they can motivate and stimulate learning. It is important that teachers experience sufficient self-efficacy, as this affects their performance and consequently the learning process of the students *(Costantino, 2008)*.

Because we expect the teacher to guide the students in the development of their STEM-competences in high-tech informal learning experiences, it is essential to know to which extent they feel well-prepared for teaching in this context and confident about their own capacities. Therefore, we conducted an international survey, which gave us some interesting insights with regard to teachers' self-efficacy.

Self-efficacy of teachers: insights from research

Participants in the study were recruited through teacher educational conferences, professional development courses and via professional teacher and Fablab networks. All teachers were affiliated with STEM (i.e. they taught at least one STEM subject), and they completed voluntarily an online survey. We received responses from 347 teachers (46% male, 54% female).

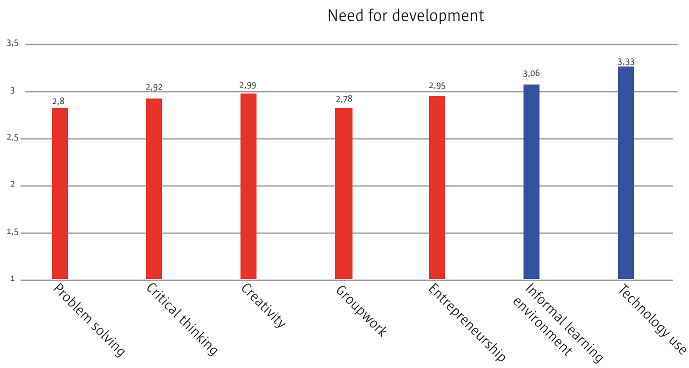


Teachers indicated how confident they felt in stimulating various 21st century competences, how confident they felt in teaching in informal learning environments and how confident they felt in using technological equipment. An example of a question is: "I have confidence in how to promote higher-order thinking among students." Teachers could indicate their answer in a range from 'strongly disagree' (= 1) to 'strongly agree' (= 4).

In general, teachers report medium to high self-efficacy for stimulating 21st century skills. The average reported self-efficacy was lowest for stimulating entrepreneurship (3,13) and highest for stimulating problem solving (3,33).

They also feel comfortable when teaching in an informal learning environment, which is reflected in an average score of 3,02. However, when it comes to technology use, they feel a lot less confident. With an average of only 1,95, teachers indicate that they do not feel confident about using technology during their educational practice.

Despite the teachers reporting quite high self-efficacy regarding stimulating 21st century skills, they still experience the need for further development. They answered the questions about development needs with an answer scale from 1 (strongly disagree) to 4 (strongly agree). For instance: "I have a need to develop how to stimulate students to be enterprising."
For the stimulation of 21st century skills, their average development needs varied from 2,80 to 2,99, indicating a medium to high development needs. (min. average: 2,80; max. average: 2,99). Not surprisingly, when it comes to their development needs for teaching in high-tech informal learning environments, teachers indicated that they could use some help in learning how to use technological equipment (with an average score of 3,33).



These results make clear that teachers could use high-quality support in helping students develop 21st century skills. Besides the focus on the development of generic competences, teachers should also be supported in working in informal learning environments and working with technological equipment.
In the Artifex project, workshops have been developed to optimally assist teachers in strengthening the 21st century skills of students, when working in high-tech open learning environments. The workshops challenge the teachers in supporting problem solving, creativity, critical thinking, group work, entrepreneurship, and teaching in informal learning environments and using high-tech equipment. Different workshops have different levels of difficulty, and are suited for other student age categories, so that each teacher can find the most appropriate workshop for his or her own competence improvement.

Experiences from teachers in the field

Teachers who are working with the Artifex workshops, or with the development of 21st century skills in high-tech informal learning environments in general, report similar experiences and perceived challenges.

Below, we have made a summary of what you can expect as a teacher when working on 21st century skills in a high-tech informal learning environment. We describe eight frequently encountered situations and observations, and if necessary, how you can cope with possible difficulties.

1. Students react enthusiastically

Students generally react very enthusiastically when challenged with the Artifex workshops. The workshops appeal to the creativity, willingness to learn, and intrinsic motivation of students. The research and design cycles provide a structured framework in which there is enough room for experimenting, creativity, and 'out-of-the-box' thinking. For instance, students are challenged with the assignment of building a pinball machine. They follow the steps of the design cycle, but are free to experiment with materials and to search their own solutions for technical requirements. The more autonomy students experience, the more their intrinsic motivation is nurtured. The enthusiasm of students is reflected in the statements of the teachers who worked with the Artifex workshops.

"The pupils were very enthusiastic about the subject from the start until the end. They had full commitment during the whole assignment, and they came up with a lot of creative ideas and applications. Engagement levels were high right until the end of the last week."

– Belgian teacher

"All students seemed to enjoy the activity and all of them were actively involved."

– Swedish teacher

"The activity was greeted with great curiosity and enthusiasm. I had no particularly high expectations, but the students worked well together and it was clear that these kind of workshops are captivating for the students and set in motion their intrinsic ability to learn."

– Italian teacher

2. 'Fun' assignments can still be intellectually challenging

The introduction of choice in the assignment and the element of joy in the learning context does not mean that the assignment is less intellectually challenging. One of the teachers who worked with the pinball machine workshop, challenged the students with the following requirements:

"I made the workshop a bit more challenging, by introducing some extra requirements. The following additional technical goals needed to be achieved: 1) the pinball machine had to comply with certain size and measurements restrictions, 2) the concept needed to differ from the classical pinball machine, so modifications are essential, 3) the pinball needs at least one automated element, such as a piece of electronics that could register a ball passing, 4) the machine needs to contain a 3D printed element and 5) all used materials need to be recycled materials."

– Belgian teacher

The assignment comprised still ample opportunities for creativity and free choice, while containing some complicating requirements. This example demonstrates that these two task characteristics do not exclude each other.

"The final designs did fulfill all expectations, with some groups clearly overachieving on the goals. Students reacted very positive to the assignment."

– Belgian teacher

3. Students with learning difficulties exhibit talents that are otherwise overlooked

Students who are typically experiencing difficulties in traditional learning environments (i.e. standard classrooms in schools), can benefit from informal learning environments. In contrast to traditional learning environments, informal learning environments have a broader spectrum of available materials that can trigger the expression of skills that are less obvious in a traditional class context, such as creativity or problem-solving skills.

The 'mastery experience' of being capable to perform well on a given task or to excel in one of the generic skills, can result in more confidence and self-efficacy. Teachers reported that some students performed unexpectedly well:

"Students worked with great enthusiasm, including students that usually have difficulties during regular school lessons. I was impressed about the skill that some children expressed, especially since those children were often labeled as 'problematic' in the regular class context."

– Italian teacher

4. There are no 'standard' problems or situations.

Every problem requires the teacher to think along with the students. Teachers do not always know the optimal solution, and even if they do, they need to be able to follow the reasoning steps of the students. In an informal learning environment, the problems are less structured than in a traditional learning environment. The fact that teachers have to 'think along' and that they also have to search for problems and solutions, is a good example for students.

"The difficulty for me was to quickly see what they had done wrong in the programming if there were errors. I made it, but it took time."

– Swedish teacher

Also, teachers have to adapt quickly and respond to activities or thinking processes that are stuck.

"As a teacher, you have to help with students to turn non-investigable questions into investigable ones."

– Italian teacher

"Although the workshops were very well prepared, you have to adapt the workshop if you see that students' age, mathematical skills or previous experiences, prevent students from successfully completing a task. A teacher has to be sensitive about what dynamics are going on in a group and adjust the task or the way a task is performed accordingly."

– Czech teacher

5. Assessments might require an alternative approach

Evaluating whether students reach the predefined learning goals can be a big challenge. When it comes to specific STEM knowledge and applications, the assessment can be done through relatively common tests (formative or summative). Rating generic skills on the other hand, is less 'objective', and thus more difficult for teachers. What is creativity? And how do you assess entrepreneurship?

"If I was allowed to choose a seminar to further develop my professional competences for these kind of workshops, I would choose a workshop that helps to assess progress and skills acquired by students."

– Czech teacher

Rather than rating the end result, it might be recommended to rate the process that led to the end result. Did students explore multiple options? Did they come up with new ideas or approaches? And how well have they worked together as a group? These are only a few examples of questions that can help to assess the learning process of students with regard to 21st century skills.

"I created observation sheets to gather information on the achievement of the objectives that I considered important for my lessons."

– Italian teacher

Some teachers like to work with rubrics to assess learning processes of students and groups, in an attempt to standardize the assessment. However, also more novel approaches for competence assessment are proposed, as the interest of the scientific educational community for evaluating competences grows *(Lesterhuis, Verhavert, Donche, & De Maeyer, 2017)*.

Open and real–life tasks, which are typical for learning in high-tech informal learning environments, can also be evaluated through comparative judgement. Instead of assigning a score to one of the (sub)criteria for each student, assessors compare two performances and decide which one is best. The idea is that even when teachers are giving scores, they are unconsciously comparing, and that the deliberate comparison of multiple students in one group, results in a more reliable outcome. This approach to assessment can help teachers in evaluating competences that are more difficult to score through traditional assessment. An example of software for comparative assessment is 'Comproved' *(Comproved, 2020)*.

6. Group work can be complicated by practical issues

Despite group work being a source of ample learning opportunities, such as co-operating, communicating and managing projects, etcetera, it can also lead to difficulties. Several teachers reported that practical issues hampered the functioning of the groups. Examples are differences in pace between individuals, attendance rate, task and time management, and personal issues. At the same time, they often mentioned good solutions to these difficulties.

"A difficulty was that the learners in the group were not working at the same pace. Some were faster, some were slower. My solution was to give more detailed individual tasks to the learners who were faster. For instance, I added more deepening and complementing exercises or introduced more complex algorithm concepts in a programming exercise."

– Czech teacher

"Difficulties were merely practical in nature. The groups consisted of three student each, but in one of the groups the attendance of the students was very irregular, eventually with one of the students ending up alone."

– Belgian teacher

"It was nice to see that all students were so enthusiastic. However, for me as a teacher, it was sometimes difficult to contain that enthusiasm. Students are not used to participate in this kind of group activities, so they did not understand very well the importance of respecting deadlines. Thanks to collective 'circle time', they were able to see what was expected, they could more efficiently share ideas and the activities were easier and clearer for students."

– Italian teacher

"There was no clear defined division of labour among the groups, and that led to some inefficiencies. A teacher can stimulate a fair division of labour by letting students explicitly reflect about task management."

– Belgian teacher

"Difficulties during the workshops were group-related. Some groups had bad time management and did not complete the full task; Other groups had some in-fighting and were not able to cooperate successfully."

– Belgian teacher

"Group difficulties were not related to cognitive abilities, but rather to the personality of the participants."

– Italian teacher

"I needed to support some groups with their cooperation."

– Swedish teacher

7. Both the presence and the absence of technology can be challenging

In high-tech informal learning environments, a broad arsenal of equipment is at the disposal of students and teachers. This can stimulate creativity and support the technical competences of both student and teacher. Many teachers acknowledged the added value of the presence of technological equipment:

"Inside the STEM lab, there was no shortage of material for the design. This leads to a lot of inspiration and creative solutions for problems. Students were very autonomous when they had so many options at their disposal."

– Belgian teacher

"In the school, the structure of the lessons and rooms is often more rigid and 'aseptic'. You have lack of space and less materials freely accessible to the students. In the Fablab, we experienced less anxiety of dirtying and ruining and this led us to experiment more."

– Italian teacher

However, teachers felt sometimes overwhelmed and uncertain about their own abilities to successfully implement the available technology. They often expressed the need for training programs, extra assistance, or clear manuals for the use of the machines.

"I would like to follow a training program that provides me with more technical knowledge. This way, I would feel more confident to approach hands-on activities in the lab."

– Italian teacher

"I don't know how to handle a 3D printer, so I definitely want to learn more about that. A 3D printer expert would come in handy."

– Swedish teacher

"I would like to follow a technical oriented education, especially for how to use and apply a microcontroller. Also, the presence of someone with a lot of technological knowledge would help me during the workshops."

– Belgian teacher

"I have taken a course in programming, but I still need to practice. A programmer who is able to detect mistakes by a quick look would help to save more time."

– Swedish teacher

However a high-tech informal learning environment is preferred, multiple workshops could also be given in a more traditional educational environment. This can come in useful when there are no Fablabs available. In the absence of technology, teachers also reported some challenges.

"Teaching in this traditional environment (while trying to do woodcutting work) is very frustrating as it limits the quality of work you can deliver. There will be more inaccuracies, mistakes or other errors because of the environment. Also, since the environment is classical, it does not inspire implementing other solutions. There is no rack with materials you can go to in order to find inspiration to solve a problem. Students rely more on the teacher to find solutions for them and to think out of the box than they would probably do in a more stimulating environment."

– Belgian teacher

"Definitely, a Fablab has a series of instruments and materials that were not available in our context of a traditional school. But we tried to accommodate this problem, by turning the creative atelier into a Fablab. The atelier contains some materials and specific instruments that could have added value. Also, the most important thing is the teacher's vision, approach and mission. This way, you can still provoke interest within students."

– Italian teacher

8. Teachers can experience an increased need for assistance

As mentioned previously, teachers often expressed the desire for more assistance when using high-tech equipment. But the needed assistance could also be of a more pedagogical nature.

"It was a challenge to manage all student groups at the same time. Often, multiple groups need your advice or help at the same time and you cannot be there for all of them at once.

– Belgian teacher

"A teaching assistant with organizational talent would be very useful to help keeping track of materials and time."

– Belgian teacher

"I would like to have an assistant without a traditional teaching background, because he or she would have the ability to simulate us to innovate without fear of difficulties."

– Italian teacher

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