Interactive Classroom Working Group

Future Classroom Lab

Makerspaces in schools

Practical guidelines for school leaders and teachers

European Schoolnet

Makerspaces in schools

Practical guidelines for school leaders and teachers

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Based on original work from Indire: Giunti Scuola (2019)
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Contents

Executive Summary

Makerspaces, which are designed for hands-on, collaborative, creative work, are a fairly recent addition to some schools in Europe and worldwide. Students in school makerspaces can work with materials such as paper, card, wood, metal, plastics, clay, fabrics, electronic components, microcontrollers, construction kits or programmable robots to create many different objects, and complete many different projects, using a variety of tools and machinery.

Teachers in 15 schools in nine countries, interviewed for this publication, described approaches to learning enabled by, or necessary in, makerspaces such as constructivist, inquiry learning, collaborative and project based; with teachers coaching and supporting rather than teaching in a traditional way.

Activities in makerspaces can include analysing objects, especially electronic, mechanical and IT devices, breaking these down and creating new objects from the pieces and knowledge acquired; as well as creating new objects by working in design cycles that lead to a solution by progressively correcting errors. Makerspaces allow students to progress from passively using objects created by others to better understanding how technologies work and creating innovative objects themselves.

Students typically start with introductory projects requiring basic knowledge of specific technologies or subjects. They progress to applied knowledge projects, that may be collaborative and inter-disciplinary, in which they enhance their knowledge and skills through problem solving activities. Students can also participate in more ambitious, long-term projects, that may simulate a professional context. These can relate to competitions that require planning, teamwork and project management skills in addition to making skills. Students working in makerspaces in several of the case study schools have participated in national or international competitions.

There is no one-size-fits all makerspace. Makerspaces in schools vary according to factors such as the level, type and size of school; the nature of the physical space available; the funding available; the interests, aims and skills of school leaders and teachers; support available from, and involvement of, industry partners, local community makers or local education authorities. As well as start-up funding, refurbishing and equipping a physical space, school leaders also need to consider how their makerspace will be funded over the longer term, how it will be managed, and how teachers will be trained, motivated and supported. Case study schools have identified four possible approaches to ensuring the long-term financial sustainability of their makerspaces: i.e. on-going school funding/fund raising; local authority funding; self-supporting communities with makers paying fees plus industry partner sponsorship; public/private partnerships.

What are you most interested in?

Topic	Where to find it
Understanding makerspaces, Fab Labs and related concepts	Part 1 Sections 1 & 2
The benefits of makerspaces and what students can do in them	Part 1 Sections 3 & 4
Teaching and Learning in a school makerspace	Part 1 Section 5
Key questions to ask	Part 1 Section 6
Types of the makerspaces	Part 2 Section 1
Planning a makerspace for your school	Part 2 Section 2
Creating and equipping your makerspace	Part 2 Section 3
Makerspace areas and toolkits	Part 2 Section 4
Sustainability	Part 2 Section 5

Introduction

The work of the Interactive Classroom Working Group (ICWG) of European Schoolnet is closely linked to the activities of the Future Classroom Lab (FCL) in Brussels, which was created in 2012 by European Schoolnet (EUN), its 34 supporting education ministries and several industry partners, to help visualise how conventional classrooms and other learning spaces can be reorganised to support changing styles of teaching and learning. The Future Classroom Lab, which is currently supported by over 30 industry partners, was renovated in 2019 and the lab surface area was extended to cover approximately $250m^2$. The new area now also includes a larger focus on the maker movement and the key ideas of makerspaces, and includes a selection of relevant equipment such as 3D printers, robotics, 3D scanners and trolleys with making components.

These guidelines produced by the ICWG is the continuation of a series of previous practical guidelines for teachers and school heads on innovative learning spaces in schools, in particular:

- Guidelines on Exploring and Adapting Learning Spaces in Schools[1] published in 2017 to provide practical advice and support to schools that are starting to explore how to develop and adapt learning spaces in order to enable the introduction of innovative pedagogies using technology; and
- Guidelines on Building Learning Labs and Innovative Learning Spaces[2] published in 2019 providing step-by-step guidance for schools on how to create their own learning labs or to adapt their learning spaces in other ways.

1 Bannister, D. (2017), Guidelines on exploring and adapting learning spaces in schools Practical guidelines for school leaders and teachers. European Schoolnet. Belgium.

2 Jill Attewell J. (2019) Building learning labs and innovative learning spaces. European Schoolnet. Belgium.

This publication focuses on creating and using makerspaces in schools and is based on:

- Research and experiences observed and analysed in projects conducted by the Italian Government's National Institute for Documentation, Innovation and Educational Research (INDIRE) in recent years.
- The experiences of schools in nine countries (Austria, Belgium, Czech Republic, Ireland, Italy, Luxembourg, Portugal, Switzerland and Turkey) that have created their own makerspaces as described in the case studies included in this publication, which are based on interviews with the schools' principals and teachers.
- Desk research focussing on makerspaces in other locations and countries.

It is divided into two parts:

Part One describes makerspaces and similar active learning environments, considers the benefits and challenges of makerspaces in schools and provides examples of how they can be used by students and teachers.

Part Two provides advice for schools related to planning, setting up and managing makerspaces plus examples of toolkits used for different types of makerspace activities.

The case studies in these guidelines are also published separately on the website by country here: *http://fcl.eun.org/icwg-makerspaces*. Moreover, each case will be illustrated by a video demonstrating how the makerspace in the school was conceived and the activities taking place. Case study teachers are directly involved in the production of the videos.

Part One

Makerspaces in schools: uses, benefits and questions to ask

1. Makerspace, Fab Lab or Learning Lab?

Readers of EUN publications will notice that there are similarities between makerspaces, fab labs and learning labs, including the Future Classroom Lab in Brussels. Also, the term fab lab is sometimes used interchangeably with makerspace.

The similarities and differences between these three types of spaces are related to:

- Their typical locations
- Who uses them
- The equipment available in them
- The activities which take place in them
- Their primary purpose and focus

The following definitions of learning labs and fab labs may help to differentiate between these innovative learning spaces and makerspaces, which are defined in Part One Section 2.

It should be noted that some schools may have both a learning lab and a makerspace. In some cases the makerspace is located within the learning lab. In addition, the dividing line between a learning space and a makerspace is not always completely clear. There are examples of some activities that are typically carried out in learning labs taking place in a makerspace (such as making films with green-screen technology) and some projects that may be thought of as makerspace activities taking place in a learning lab (such as making robots).

However, how spaces are used, the activities carried in them, the ways in which they contribute to transforming teaching and learning and the benefits accrued to learners are all more important than the name used to describe the spaces.

Learning Labs are usually located in schools, colleges or universities and are used by the students and teachers in these institutions. They are sometimes also used by students and teachers from other institutions. Learning labs are flexible learning spaces that allow for easy reconfiguration according to the needs of the learning activity. Their mission is to host innovative learning through learning activities that incorporate new visions of pedagogy, key competences and technology enhanced learning. Learning labs also seek to involve and connect different stakeholders and to encourage an open culture.

Many learning labs in European schools, and some others around the world, were inspired by the Future Classroom Lab (FCL) in Brussels. The FCL concept contains some elements of making as a methodology. It is therefore unsurprising that, after creating and using their Learning Labs, some schools decided to develop dedicated makerspaces or making zones.

For example, the principal of one of the Portuguese case study schools explained that "*the option of setting up a makerspace became a need when our FCL inspired ActiveLab was unable to cater for all the active learning activities the teachers and students wished to undertake*".

School leaders from Dr Edvard Benes Elementary School in the Czech Republic also say they were motivated to innovate in their school after visiting the Future Classroom Lab in Brussels. However, as they developed their ideas further they decided to create an innovative learning space that combines elements of both a learning lab and a makerspace.

Fab Labs are in some ways very similar to makerspaces but have their own specific ethos. Fab Lab is an abbreviation of fabrication laboratory, and they were initially intended to stimulate local entrepreneurship by providing dedicated spaces for technical prototyping, innovation and invention. Fab Labs started in 2005, and were initially inspired by a Massachusetts Institute of Technology (MIT) course called "*How to Make (Almost) Anything*". Today the term Fab Lab can refer to either: organisations that are part of the network run by the Fab Foundation; or it can be used as a generic term for similar spaces.

Activities in Fab Labs include peer-to-peer project-based technical training and local problem-solving as well as small-scale high-tech business incubation. The basic ideas are:

- There is a core set of tools that can enable anyone to make almost anything after a brief introduction to engineering and design.
- Fab Labs should be open to the public for little or no cost.

Fab Labs have also become places dedicated to learning in which users can play, create, learn, share knowledge, invent and connect to a global community of students, educators, technologists, researchers, makers and innovators.

Makerspaces may be:

- Located in, and exclusively used by, a single school or educational institution.
- Shared by more than one school or with other types of educational institutions.
- Located in communities, as part of a library or as independent spaces.
- Mobile, located in a bus for example, and visit different schools and/or communities.

Most of the makerspaces discussed in the case studies referred to in this publication are located in schools as this was the intended focus of the investigation.

School-based makerspaces are often open to the local community outside of school hours, and schools may collaborate with external individuals or organisations to set up and manage their makerspaces.

2. What is a makerspace?

Makerspaces are physical spaces designed for hands-on, collaborative, creative work.

The activities and experiences of learners, including students and adult lifelong learners, in makerspaces can be seen as a progression along a continuum from their being users of things created by others to actively creating something innovative themselves.

The uTEC Maker Model, created by David V. Loertscher, Leslie Preddy and Bill Derry[3], describes the activities, strategies actions and roles of learners in this process.

The uTEC Maker Model, adapted from Loertscher, Preddy and Derry 2013

Other writers and makers have added that tinkering can include working in design cycles that lead to a final solution by progressively correcting errors.

Makerspace activities can also include analysing the functioning of objects, especially electronic, mechanical and IT devices, breaking these down and creating new objects from the pieces and the knowledge acquired.

The aims of activities in makerspaces, and the aims of the maker movement, have been described[4] as to:

- Create a context that develops a positive approach to problem solving and encourages students to believe that they can learn to do anything.
- Identify, develop and share a wide variety of projects, based on a wide range of tools and materials that relate to the interests of students inside and out of school.
- Encourage the development of a philosophy based on collaboration between students, teachers and the community.
- Develop educational contexts that link the practice of doing with formal concepts and theories, to support discovery and exploration, introducing new design stumbling blocks and new ways of thinking about the creation of objects.
- Promote in each student the full capacity, creativity and confidence to become agents of change in their personal lives and communities.

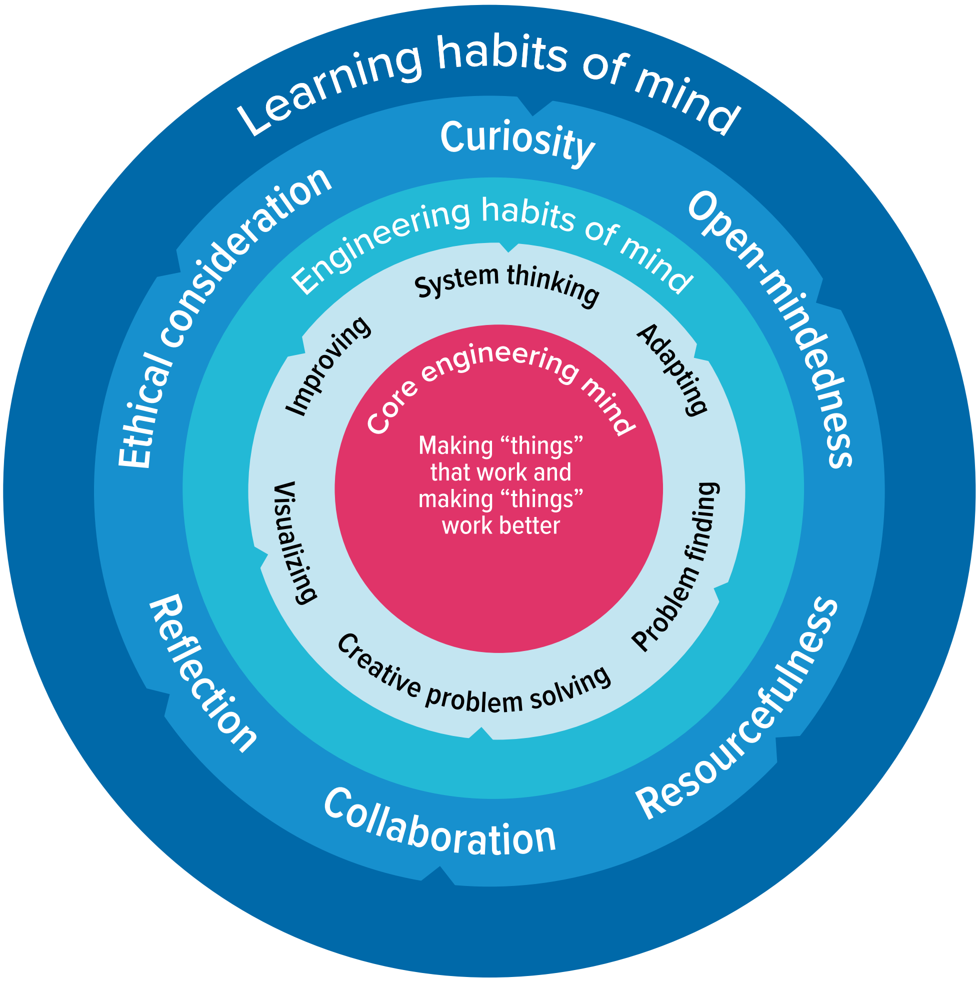
It has been suggested that the attributes, and approach to learning, of students using makerspaces should be similar to those of professional engineers. A report for the UK's Royal Academy of Engineering Standing Committee for Education and Training, "*Thinking like an engineer: Implications for the education system*"[5] observed that '*engineering habits of mind*', which are needed to make things work and make things work better, plus '*learning habits of mind*' are required for studying STEM[6] subjects.

3 Loertscher, David V., Leslie Preddy, and Bill Derry. "Makerspaces in the School Library Learning Commons and the uTEC Maker Model," Teacher Librarian, vol. 41, #2, December, 2013, p. 48-51

4 Hlubinka, M et al, 2013, "Makerspace playbook school edition", Maker Media.

5 www.raeng.org.uk/thinkinglikeanengineer

6 Science, Technology, Engineering and Mathematics



Thinking like an engineer for learning

3. What students can do in makerspaces

Research by INDIRE has found that students typically make use of makerspaces to undertake three types of projects:

- **Introductory projects:** short projects, perhaps within specific teaching units, that offer students the opportunity to carry out activities that require basic knowledge in a technical and disciplinary domain.
- **Applied knowledge projects:** interdisciplinary projects that require students to enhance and augment skills acquired in the introductory laboratories through problem solving activities.
- **Long-term projects:** ambitious projects, that may simulate a professional context; designed, proposed and implemented by individuals or, preferably, teams. These projects may be related to competitions for students and require project management as well as making skills.

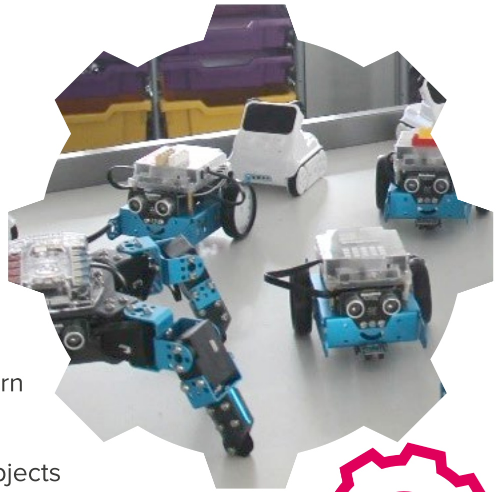
Several of the case study schools mentioned that their students had completed makerspace projects in the context of national or international competitions.

Students at Tofaş Science High School in Turkey have also worked on ambitious projects in collaboration with engineers from the commercial company which built their makerspace.

Teachers at Freixo school in Portugal suggested that activities in their makerspace:

- *"Highlight the skills of programming and use of digital tools, allied to the Internet of things".*
- *"Allow students to go beyond the formal curricula, favouring the development of individual and of collective projects with the use of current materials and tools".*
- *"Create a hotspot for developing competencies for the 21st century".*

Evidence from the case studies includes the following examples of things students can make or do in school makerspaces:



- Circuits with lighting effects
- Circuits with sound effects
- Wearable circuits
- Projects with motors and switches
- Simple robots that draw, jump, run
- Programmable robots that function with the help of installed sensors
- Use a game combining physical cards and an app to learn coding
- Projects involving constructing and programming flying objects including rockets and drones
- Dismantling and reconstructing mechanical, electrical and electronic objects
- Construction of wooden clocks, some with LED light circuits
- Creation of musical instruments
- Designing and 3D printing simple objects
- Designing and 3D printing parts used in constructing complex objects
- Constructing a 3D printer from a kit
- Projects involving the use of ropes, fabrics or leather
- Mechanical design with the use of levers, gears and pulleys
- Paper and cardboard constructions
- Architectural modelling
- Projects involving analogue photography including use of a darkroom
- Use of playmobile figures and video cameras to make stop motion animation films

Most of the case study schools have found that it is important to allow students to use their own ideas to initiate at least some of the projects they undertake in their school's makerspace and it can be good to combine fun and learning.

The makerspace manager at Baar school in Switzerland gave an example: "*projects can be initiated by students perhaps in response to an event or situation e.g. students celebrated the school dog's birthday by building a Makey Makey*[7] *piano to play happy birthday*".

7 Makey Makey is an electronic invention kit, see makeymakey.com

The research and experiences of Paulo Blikstein at Stanford University[8] highlight types of makerspace activities which should be encouraged or avoided. Those to be encouraged include activities that:

- Include *"multiple cycles of design, and new levels for both frustration and excitement, which students normally do not experience in their normal school experience"*.
- Do not involve *"artificial boundaries between disciplines"* and therefore result in *"a more diverse and accepting intellectual environment"*.
- Contextualise learning in STEM subjects, for example *"abstract ideas such as friction and momentum become meaningful and concrete when they are needed to accomplish a task within a project"*.

To be avoided, or used sparingly, are activities where "*digital fabrication machines might generate aesthetically pleasing products with little effort*" by the student. Instead he advises that teachers should encourage students to undertake "*more complex endeavours*".

4. The benefits of makerspaces

Research carried out by INDIRE identified the following advantages of makerspaces, which have been confirmed by evidence from the case studies that have informed this publication.

- **Support for mixed ages and interdisciplinary learning**

A makerspace can be divided into different areas allowing groups of students to carry out educational activities designed specifically for their abilities and tailored to their age group. In addition, activities carried out in makerspaces may not be directly linked to an individual discipline such as physics or chemistry, as is often the case with a normal school science lab. The new environment is a space for sharing practices and knowledge, both from the point of view of the tools, machinery and materials used and as regards the interdisciplinary approach to teaching and learning.

- **Collaborative development of teachers' skills and lesson plans**

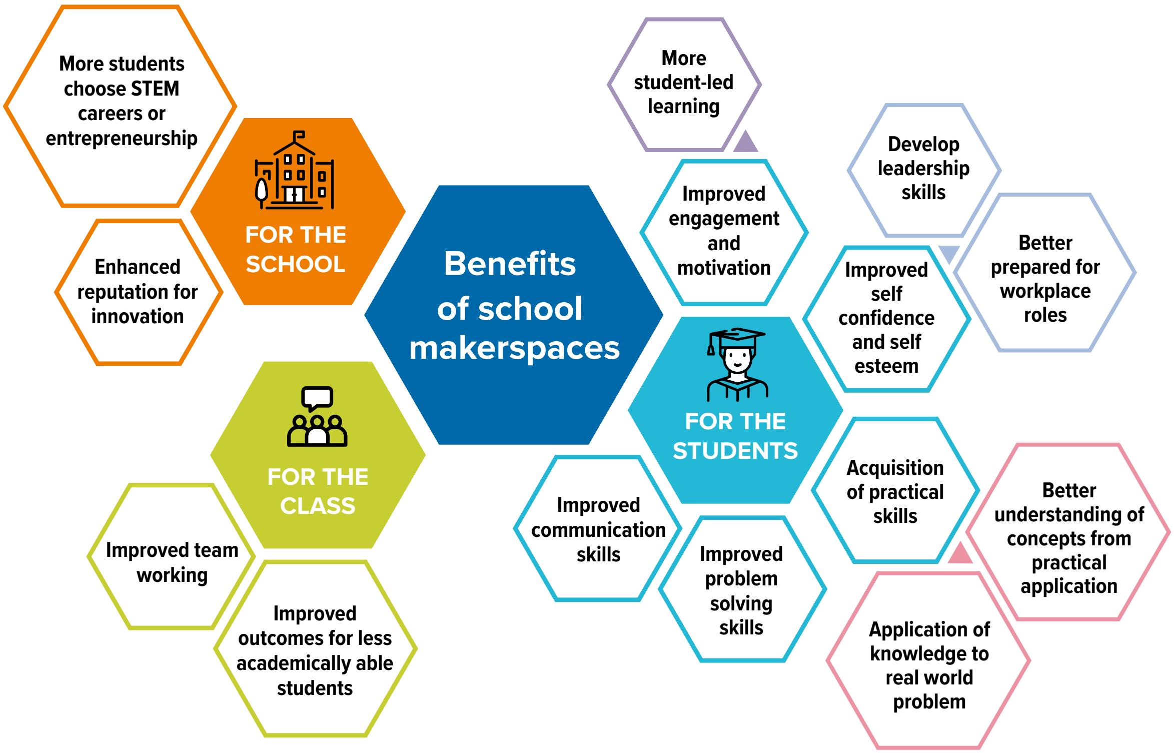
A properly managed makerspace, especially when activities are fully documented, is a place where a teacher feels part of a community of good practice. Teachers can design new lesson plans based on their own ideas, or customise activities already tested by other teachers. In an ideal situation, a teacher approaching a makerspace will find within it competent colleagues and external technicians or makers who will support them and help them to grow professionally. As they use the makerspace, teachers should find that it stimulates their – and their students' – creativity, and helps them to develop competences in making and supporting students' making. The resulting structured and well-documented teaching units or lesson plans will add to the school's repository of teaching assets.

The School Director Istituto Comprensivo Lucio Fontana in Italy says their experience has confirmed these benefits of makerspaces and emphasises that "*peer tutoring, collaborative learning and interdisciplinary projects are usual approaches to activities in the makerspace, and they are effective*".

The case study schools have identified the following examples of added value or benefits resulting from setting up a makerspace and there was a great deal of consistency across all schools and all countries.

The teachers, and the School Director, at IC Lucio Fontana mentioned nine of these benefits and their Digital Manager added that also "*students enjoy working in the makerspace because it is a more informal learning space, full of stimulating objects and tools, ready to be used and tested. They also like to use technology to make their own projects*".

8 Blikstein, P (2013), "Digital Fabrication and 'Making' in Education: The Democratization of Invention" in J Walter-Herrmann & C Büching (Eds), "FabLabs: Of Machines, Makers and Inventors", Bielefeld: Transcript Publishers.



Summary of makerspace benefits from case studies

- **Improved student engagement and motivation**
  - Students are motivated and engaged by the makerspace activities.

    An Irish teacher has found that students are **“***far more engaged in scientific processes and more likely to experiment with hands on experience”* and a Turkish teachers says *“the atmosphere of the makerspace increases students’ motivation and provides them an environment for production. Therefore, students get to learn without getting bored and learn permanently”.*

  - Students are able to, and encouraged to, try out their own individual ideas and are, therefore, very involved and invested in their projects.
  - Students enjoy working in the makerspace setting.

    As an Austrian teacher observed *“they love to do projects of their own choosing and interests”.*

- **More student-led learning**
  - A Czech teacher observed that students are more active learners in the makerspace and "*they are encouraged to search information, to explore, to plan their work, to take responsibility for their tasks and to agree roles in teamwork*".
  - One of the Swiss teachers commented that giving teenagers an opportunity to work on their own projects in a makerspace enables them to "*develop a personal relationship with a place of learning*".
  - Teachers at Montessori-Bilotti school in Italy think it is important that "*Students can build and reinvent knowledge, discovering as scientists do rather than just reproducing information presented to them*".
- **Improved student self-confidence and self-esteem**
  - An Irish teacher commented on how the makerspace has "*contributed to the development of confidence amongst pupils and a willingness to try new activities that don't always work*".
  - A Turkish school principal says that "*improvements in some students' confidence and ability to work independently have exceeded the teachers expectations*".
  - An Irish teacher commented that students are proud to take what they have created home "*giving their parents or guardians an opportunity to see what their children are doing and achieving. As well as contributing to the pupils motivation this also extends their learning beyond the classroom as they explain to parents or guardians how they built a particular object and how it works*".
  - A Swiss teacher has noticed that "*students are finding out that failure is part of learning and that they can find ways around problems, this strengthens their self-esteem*".
- **Acquisition of practical skills by students**

  Students develop expertise in using a wide range of equipment, tools and materials and it is not possible to work with such a variety of tools in a traditional classroom. A Czech teacher also emphasises the importance of students being "*not only users of technological devices (such as iPads or 3D printers) but also learning how these gadgets work*".
- **Improved student understanding of concepts and topics from practical hands-on learning experiences**
  - An Irish teacher noted that "*handling the diodes, resistors, breadboards, micro:bits, and other components is helping pupils to develop a very real understanding of science, technology and engineering*".
  - A Turkish mathematics teacher has found that "*some students struggle to understand concepts when they are presented in a two-dimensional way e.g. the properties of a pyramid shape are easier to understand by building a model rather than by looking at a drawing*". He also commented that students "*give you much more complex and sophisticated answers than you expected*". Indeed, he says, "*sometimes students explore ideas so far that the teachers don't even know the topic that well*" but he considers this a great opportunity for both the teacher and students to learn.
- **Students learn to solve difficult and complex problems by trial and error**
  - A Swiss teacher has found that students therefore are "*more creative; learn by doing, not just by remembering what they are told; and learn to act independently from teachers*".
  - An Austrian teacher noted that "*students become more resilient as they learn how to use development failures in a positive way to improve their designs resulting in development of better artefacts*".

- **Improvements in team working**
    - ▶ A school principal in Turkey has observed that "*students in schools with higher rates of achievement, or in science high schools, can be rather self-centred. In the makerspace, they have to work together as a team and learn to share; this may be the most important benefit*" and an Irish teacher reports that he has "*seen a lot of improvements in pupils' communication skills and their ability to solve problems within a team*".
    - ▶ A Portuguese teacher has been impressed by the "*increased development of collaborative work skills and sharing of both resources and knowledge resulting from project-based learning*" within the makerspace.
- **Improvements in students' communication skills**
    - ▶ Teachers in an Irish school noted that students' work in the makerspace "*helps them to develop strong oral language and presentation skills*".
    - ▶ The makerspace coordinator at a Turkish school reported that their students' communication skills in English have greatly improved "*as they present project ideas and outcomes to the sponsoring company in English*".

- **Students better understand how knowledge gained can be applied to real world problems**
    - ▶ A Turkish student who worked in her school's makerspace participating in a robotics competition. Later, told her teacher that during the school summer break there was a leaking tap in her home which she fixed by changing the seal herself instead of calling a plumber. Before working in the makerspace, she would not have been able to work out how to fix the tap.
- **Students can develop leadership skills and prepare for workplace roles**
    - ▶ A Portuguese teacher saw benefits in the fact that "*students with more experience are encouraged to teach specific techniques to beginner learners*".
    - ▶ Teachers in a Swiss school noticed that students using the makerspace develop "*improved leadership skills, when they have had coordinator responsibilities" and that they have a unique opportunities to "learn about master-apprentice or superior-subordinate relationships in preparation for workplace hierarchies and discipline*".

- **Improved inclusion and outcomes for less academically able, or inclined, students**
  - An Irish teacher reports that "*the makerspace approach is very inclusive and is of enormous benefit to students who have learning difficulties, all of whom can fully engage and contribute within this environment. As there is such a range of activities there is always a role for everyone, irrespective of academic ability*". Another teacher at the same school has noticed *"boys and girls being equally interested"* in working in the makerspace.
  - A Swiss teacher noticed "*Less academically able students have more opportunities to demonstrate what they can do well. Conversely, some students who are very creative in class can find the unstructured approach in the makerspace rather daunting*". This is consistent with research indicating that students have different preferences concerning the way they learn and some are kinaesthetic learners who learn better by carrying out physical activities.
  - A Turkish school found that a student who had "*previously had an average level of academic achievement has excelled in makerspace projects. So much so that he was chosen to participate in one of the biggest science fairs in the USA*".
- **More students are inspired to choose careers in STEM fields or to become more entrepreneurial**
  - The makerspace coordinator in a Turkish school has observed that a very high percentage of the school's students are encouraged by their parents to study for a career in medicine. However "*now, many students who have interacted with engineering tools and concepts have realised that engineering is the right choice for them*".
  - The Czech headmaster observed that "*many competences, skills and mindsets are developed in the makerspace*" including "*inventiveness*" and "*entrepreneurship*".
- **A makerspace can enhance a school's reputation for innovation**

  A teacher at a Turkish school reported that "*One of the reasons that the school was among the top five schools in Turkey is having the makerspace. Students say that they have chosen the school for the innovation classroom".*
- **Makerspace activities can be especially relevant to some school priorities**

  As HTL-Hollabrunn in Austria is a technical school, where subjects studied include project development, project management, electronics and computer aided drawing, they see a makerspace as particularly relevant and have found their teaching can be enhanced by using the makerspace.

  Alexandra College Junior School in Ireland say they have a Froebelian ethos[9] which supports and encourages collaboration and play based learning which is very consistent with their setting up a makerspace.

  The Swiss case study schools have pointed out the Swiss German primary schools have traditionally offered woodwork as part of the curriculum and although, with the introduction of new curriculum, less time will be dedicated to the subject there is a clear link between these "*werken"* classes and the new makerspaces.

  The headmaster of the Czech case study school says the makerspace is consistent with their aim of striving *"to prepare students for their future careers and for life in the 21st century; to educate students to be active citizens in a changing world where digital technology will play a bigger and bigger role and will influence different aspects of their lives. Students have to understand how technology works, but they also need to be pro-active, responsible, to have communication and collaboration skills*".

9 Friedrich Froebel, a German educator who invented the kindergarten, believed that humans are essentially productive and creative, and he sought to encourage the creation of educational environments that involved practical work and the direct use of materials.

5. Makerspaces and pedagogy

5.1 Approaches to teaching and learning

Teachers in the case study schools described specific pedagogies enabled by, or necessary in, their makerspaces as:

- Constructivist learning or learning by doing
- Inquiry learning, including learning by trial and error, seeing failures as part of the process
- Making design decisions based on real experiences
- Collaborative learning, including working in teams
- Coaching and supporting students rather than traditional teaching
- Project-based methodology

The project team at Primarschule Silberberg, Thayngen in Switzerland suggested some differences between "*makerspace activities and regular teaching*" as follows:

Project work in the makerspace	Regular curricular teaching
The students decide what they want to build and with whom.	The teacher decides what to build.
Different products are developed in parallel.	All the students build the same artefact.
There are few step by step tutorials, students work from examples, materials and inspirations.	The students are given clear and structured guidance.
The goal is to try new ways of doing things, to build prototypes.	The goal is to reach the most accurate and perfect implementation possible.
The students use their prior knowledge and acquire information and knowledge in context.	The students are extensively prepared for the task.
The students develop their own evaluation criteria and they also evaluate the process.	The students' products are evaluated on the basis of predetermined criteria.

5.2 Supporting and scaffolding students

Some case study school interviewees have found that some students who excel in a traditional classroom may need help to adjust to makerspace learning. These students can "*find the freedom of the maker space a bit disorientating*".

Similarly, whilst students with special needs or learning disabilities can gain self-confidence and self-esteem by making things in the makerspace, they can be overwhelmed if simply told to go ahead and make what they want. These students need to be carefully introduced to the space, tools and materials and then encouraged and supported to use these.

When working on longer term projects, especially in the context of competitions, students may need guidance regarding planning and time management.

5.3 Collaborative teaching and learning

Collaboration is a significant aspect of makerspaces and can occur:

- between learners,
- between teachers of different subjects in a school,
- between teachers working in different schools,
- between teachers and learners,
- between teachers or learners and external experts or makers,
- between teachers and external researchers,
- between learners and sponsoring companies,

and increasing collaboration and team working is often one of a school's motivations for setting up a makerspace.

At HTL-Hollabrunn school they find that collaborations between teachers and students of different disciplines are often necessary to complete projects. In Italy, the Montessori-Bilotta school teachers say "*we share our activities with each other and we can count on maker collaboration both for the design and to lead lessons with students into the space*".

Also in Italy, at IC Lucio Fontana, the science teacher described how he prepares a draft lesson plan which he shares with the makerspace manager to get suggestions regarding both technologies and how to organise the workflow. He notes that "*workflow can be important when the students use slow machines like 3D printers*". Another teacher at the school added that they work with the makerspace managers both to design the activity and to support the students when they are working in the makerspace. Indeed the makerspace manager has become a "*second reference person who students can ask for help"*. The teachers emphasised that the makerspace managers, due to their qualifications and experience, understand pedagogy and the school's priorities and, therefore, are able to effectively support the teachers as well as the students.

At Portugal's Fernando Casimiro school "*a major objective of the school is to implement more collaboration activities, so teachers are encouraged to work in collaboration, supported by the pedagogical teams*" and Freixo school add that collaboration can include working with colleagues from other schools.

The mathematics teacher at Tofaş Science High School in Turkey says that if his students want to carry out a project involving electrics and coding then he enlists the help of the physics teacher and they regularly discuss activities, including *"the kind of method we should adopt and how we should create the project".* However, he says *"we can't assign projects jointly because the system doesn't allow different evaluation".*

Also, the geography teacher at the same school says *"When projects have direct connections with physics or chemistry, I consult to the relevant subject teachers".*

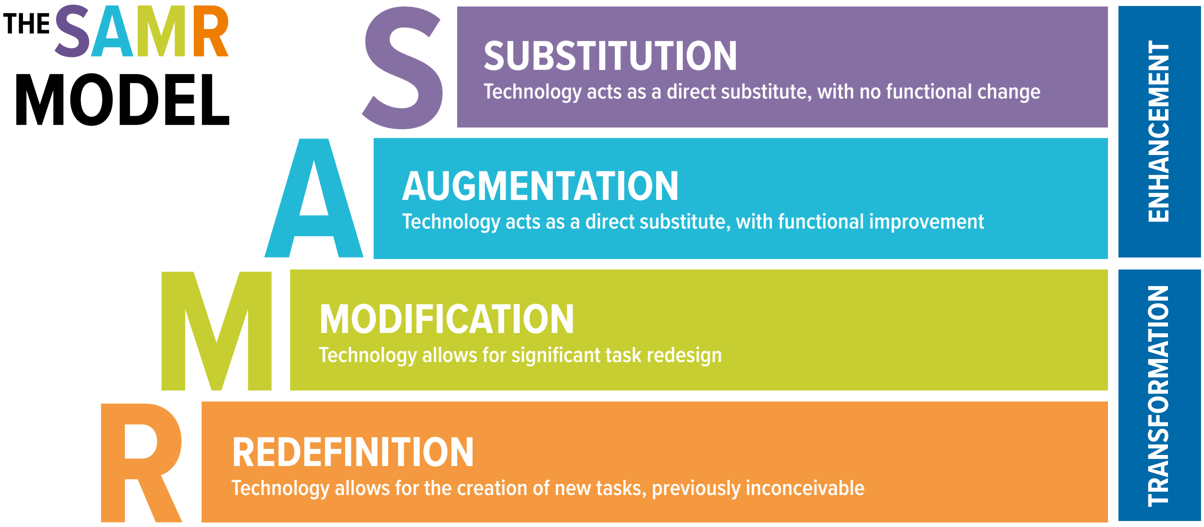
Some teachers have commented that they especially value the opportunities to work alongside, and learn with, students**.** An Irish teacher was told by one of her colleagues that in the makerspace she is *"comfortable in saying she does not always have the answers or know why something has gone wrong"* and encourages her students to work with her to find answers. A Swiss teacher also says she appreciates the way that *"teachers and students can work together to find solutions*" and agrees that "*the new environment and tools help teachers to admit they do not know everything*".

The school in the Czech Republic has found that teachers who start to teach in a different way in the makerspace also change their teaching methods in standard classrooms "*as the makerspace forces them to use more collaborative activities, they get used to this type of working and then* *start to use more collaborative activities in standard lessons*". Pedagogical support for teachers also sometimes includes "*tandem teaching*" in which the makerspace manager helps another teacher to use various technology devices during their lesson. This involves "*working together with the teacher in advance to plan each lesson, including choosing the topic and the technology as well as preparing meaningful activities*".

At Sint Lucas school in Belgium, the idea of a makerspace was very new to teachers, so at first they practised co-teaching. This enabled pairs of teachers to work on differentiation and to learn from and support each other. A teacher commented that this is a "*a big advantage in a digital world that changes very fast*".

5.4 Makerspaces and the SAMR model for transforming teaching and learning

When a makerspace is first created, a school may decide to adopt an incremental approach to starting to use the new environment to firstly enhance and later transform teaching and learning. This approach is informed by the SAMR[10] model. The Substitution, Augmentation, Modification, Redefinition (SAMR) model describes a series of four steps in the process of integrating new technologies into teaching and learning.



The SAMR model (redrawn for wikiversity.org by Lefflerd)

Research by INDIRE suggests that when designing learning activities for a school makerspace the SAMR steps are:

- **Substitution**: the new space is used to carry out activities consistent with current approaches to teaching and learning. This establishes the makerspace as relevant to the school's curriculum whilst the teacher and students become familiar with the space and the maker philosophy.
  - An example for this activity is primary students producing gifts for their parents. In some schools, students create objects using low costs materials. These objects can be produced by using 3D printers or other machines, and make both teachers and students aware of using these new machines for creating outputs.
- **Augmentation**: the teacher starts to introduce different technologies and approaches, but the activities are essentially the same as before the makerspace was set up.

10 Ruben R. Puentedura, Transformation, Technology, and Education. (2006), online at: http://hippasus.com/resources/tte/

- ▶ Students can then “augment” these gifts using more than one machine, combining different parts, or different ways to create; such as the 3D printed gift can be combined with a blinking led using Arduino.[11]

- **Modification**: the teacher begins to re-design activities in ways enabled by using new equipment and skills, supported by the makerspace coordinator/technician and feedback from students.
  - ▶ Once teachers and students are able to use different machines and teachers increasingly collaborate with the makerspace coordinator/technician, new kinds of activities can be tried out by modifying activities they already have designed. For example, a science activity based on observation of the effects of light on plants can be strengthened with light sensor tools created with Arduino in middle schools to measure the value of light during time, or students in primary schools can add 3d objects to supplement their drawings for their history homework.

- **Redefinition**: the teacher re-designs activities, and the relationship between practical activities and the theory of their subject and of other disciplines, in ways that could not be delivered outside of the makerspace environment. The coordinator/technician supports and encourages new activities and students are encouraged to propose activities.
  - ▶ Once teachers see that students are confident using the tools and machinery safely and are capable of organising their activities in the makerspaces in a given timeframe, new activities related to real life problems can be created based on different topics and in collaboration with the makerspace coordinator/technician. For example, students can create something to help birds in the school park (or another park where students can develop a school project). This activity can be part of a long-term project involving observations and studying plants and birds in and around the park, which affect birds’ lives, and identifying problems and solutions using the makerspace.

However, some schools – such as Baar school in Switzerland – have adopted a different approach. Here the makerspace is initially operating as a separate environment, deliberately not too closely linked to mainstream learning and the curriculum. Students using the makerspace are supervised by the makerspace manager who suggests projects for them to work on. Separately, teachers use the makerspace for their professional development and, when they have the confidence, borrow sets of equipment and material to use in with their students in their classrooms. In the longer term it is envisaged that the makerspace will be more integrated into the curriculum and teachers will work with their students in the space.

5.5 Highly structured and guided or more informal student-led activities?

Some researchers emphasise a vision of makerspaces as “*playgrounds for tinkering and construction*[12]”, focussed on nurturing creativity and innovation. An example of this approach is the Base 1 makerspace in Luxembourg, which is located within a youth work resource centre and shared by local schools and aims “*to provide a boundary free environment for students where they can evolve their own project ideas in a creative manner*”.

However, others have noted that in schools pressures of time and curricula can result in less creativity and in activities which are more limited and controlled.

11 Arduino is an open-source electronic prototyping platform enabling users to create interactive electronic objects https://www.arduino.cc/.

12 Kurti R S, Kurti D L, Fleming L, “The Philosophy of Educational Makerspaces Part 1 of Making an Educational Makerspace” Teacher Librarian 41(5), 2014

Primarschule Silberberg, Thayngen in Switzerland are currently discussing this issue as they plan for a future with fewer staff dedicated to supporting the makerspace, as the initial research project that funded creation of the space comes to an end. The makerspace manager says the question the school is asking is "*How can the school limit the choice of activities to something more manageable for teachers without stifling students' creativity?*".

One way to resolve this tension between highly structured and more informal student-led activities is to allow students access to the makerspace outside of school hours to pursue whatever projects or activities they are interested in. This approach has been adopted at Tofaş Science High School in Turkey, where students can use the makerspace in the morning before lessons start, at lunchtime and between 4.30pm and 11pm in the evening. This is in addition to carrying out more teacher directed, curriculum relevant activities in the space during timetabled school hours.

Teachers in case study schools have described how they go about developing activities for students to carry out in their makerspaces. In some cases this includes providing a great deal of information and structure for the students, whereas in other cases students are required to take more responsibility.

Teachers at Scoil Íde school in Ireland create lesson plans including instructions, visuals and photographs. Every lesson begins with an introduction to the science behind the activities and demonstrations of how to get started. The teacher may use an example from Instructables[13] to talk through the lesson or other activities are found online and adapted for use with the Irish curriculum. Alternatively, the teacher may develop a lesson themselves using tools like Lego Mindstorms[14].

Also Scoil Íde school, teachers have needed to address the challenge of finding effective ways to conduct assessment within a makerspace lesson. The idea of recording what students are doing, and pupils creating their own digital stories outlining their process within a makerspace activity is something the school would like to develop further. This would complement the school's e-portfolio development.

A teacher at Fernando Casimiro school in Portugal explained that the methodologies they use have been informed by Future Classroom Lab guidelines and guidelines on the use of active learning methodologies and *"We started by defining the methodologies before having the spaces designed and teachers were trained in the pedagogical uses of the space"*.

The makerspace coordinator at Baar school argues that **"***Activities should not be as guided as in regular lessons, but students need well organised information about how to start*" and similarly "*teachers do not need to know everything about a tool before introducing students to it" but "it is important to know the first steps very well and to solve initial difficulties otherwise students can become discouraged*".

She goes on to suggest that "*for the more advanced features of tools and more complex uses of them, teachers and students can learn together*". This may include searching the Internet for information and solutions in a competitive way when the teacher says "*let's see who finds the answer first?*".

13 https://www.instructables.com/teachers/

14 https://www.lego.com/en-gb/themes/mindstorms/about

The makerspace manager at Dr Edvard Benes school, Praha – Čakovice, in the Czech Republic has found that "*Frequently students are more confident and competent in using digital technologies than some of their teachers*" and that "*this means a teacher can be in the situation where they ask their students for help and this can lead to a better relationship between teacher and students*".

At Silberberg school each class works on two maker projects, one is focussed on acquiring skills they need and learning about the health and safety regulations in the makerspace. The students then organise their own work, and make plans to complete a product and to make a film about it in the 4 X four periods time frame.

Teachers at IC Lucio Fontana in Italy say they find particular topics which might be more effectively taught using an active learning approach and then "*we use our creativity to propose an activity (or we use our colleagues' creativity by proposing one of the activities stored in the digital archive of educational materials).*

There is no right or wrong answer, you will need to discuss and decide what is best for your school and your students.

5.6 Links between makerspace activities and curriculum subjects

In most of the case study schools, activities in their makerspaces are closely linked to the curriculum and this may be necessary in order for the school to obtain the necessary support and sufficient funding to set up and maintain the space. At Freixo school in Portugal, a teacher says "*The makerspace is seen as a resource to support the curricular activities".*

You may, however, decide that what you are trying to achieve by setting up a makerspace is best achieved by keeping it somewhat separate from normal school activities. This is the approach currently favoured by the makerspace manager at Baar school in Switzerland. She says "*integration of all makerspace activities into the curriculum is not an aim of the school's makerspace. This is because it is seen as a good thing for students to have opportunities to work in a different context outside the pressures of the curriculum".* Although, there are links to the curriculum and "*some of the activities developed and successfully used in the makerspace have become part of the curriculum*".

Teachers at the Montessori-Bilotta school in Italy *"ask students to produce some artefacts to answer to a specific curricular question*". They then add a foreign language activity by requiring the students to describe what they have done in another language. There are also links to mathematics and science as producing the artefacts require students to take measurements and act like scientists.

The mathematics teacher at Tofaş Science High School in Turkey says activities in the makerspace are always closely related to the curriculum as "*the starting point is some aspect of the curriculum but then there is expansion depending on students' vision".*

5.7 Finding ideas and resources for makerspace activities

Case study schools typically recommend attending conferences and workshops to get ideas for developing activities for a makerspace. They have also found that some teacher training colleges have developed resources that schools can base makerspace activities on. Teachers in Ireland said they would love to be part of a network where they could access tried and tested lessons and discuss lesson ideas with other like-minded teachers.

Teachers in all countries search on-line for activities, project ideas and useful resources. One source of information, advice, ideas and resources for makerspace activities is makerspaceforeducation.com. A useful source of advice on how to organise activities related to coding aspects of makerspace projects is the teaching resources page[15] of the codeweek.eu website.

15 https://codeweek.eu/resources/teach

This website also provides training materials and tailored lesson plans[16].

Many schools use the Moodle learning management system, which provides a dedicated virtual space for teachers to upload learning materials and teaching scenarios for others to use, to share teaching tips and to provide links to useful resources. In the Czech Republic, on Dr Edvard Benes, Praha - Čakovice, school's Moodle, "*content is structured according to subjects and educational areas with several sections focussing on using digital technologies for teaching e.g. tips on using Ozobot programmable robots in English or in Geography*".

The suppliers of some of the tools schools use in makerspaces provide lessons examples or space for teachers to share lesson plans on their websites. For example:

- Ozobot encourages teachers to upload lessons and offers small incentives, e.g. t-shirts.
- BBC micro:bit provides downloadable lesson plans that are aligned to Code.org[17]'s Computer Science Fundamentals curriculum for primary and elementary school students.
- The makers of the Makedo cardboard construction kit have an on-line Makedo Hub[18] where teachers can find a collection of project ideas, creations and case studies. They can also upload their students' creations as examples for others. Published uploaders receive a 10% discount coupon to purchase more kits.

6. Key questions to ask

Setting up and using a makerspace in a school presents many challenges and schools have more or less difficulty addressing these dependent upon factors such as their location and culture, financial circumstances, leadership and the amount of assistance they can gain through partnerships or sponsorship. Evidence from the case studies suggests some key questions to ask when discussing whether and how your school should set up a makerspace. Consideration of the following questions, plus others which will be suggested by your specific motivation and aims (see Part Two, Section 2.1 "What do you want to achieve"), will help you to anticipate or avoid future difficulties.

Money matters

- How will you obtain the funding needed to create and equip a makerspace?
- How can you arrange on-going funding to pay for maintenance and replacement of equipment?
- How will you meet the cost of maintaining adequate staffing to manage the makerspace and support activities?
- Can you find a way to enable the makerspace to be autonomous, both financially and administratively?
- How will you balance open access against the need to look after expensive equipment?
- Who will open the makerspace after school and during weekends to enable students and external users to work on projects? If a teacher or an external maker does this will it be on a voluntary basis? If not how will they be compensated?

16 https://codeweek.eu/training

17 Code.org is a non-profit organisation dedicated to expanding access to computer science in schools and increasing participation by women and underrepresented minorities.

18 https://know.make.do/

The space

- Is a suitable room available or is there a space that can be refurbished?
- Will school staff design the layout of the space or will you use a specialist contractor or a partner organisation? *Small school makerspaces are typically designed in-house. Large or shared spaces may involve a specialist designer, sometimes paid by a sponsoring company*.
- Who will carry out refurbishment or redecoration work?
- Is local authority permission and collaboration necessary? What is the process for this?
- Will you allow use outside of school hours or share use of the makerspace with external users? If so, will you need an access door separate from the school entrance door?
- How will you arrange timetabling? *This can be particularly difficult if the space is used by classes, for teacher training, for individual students' project work and by external users.*
- How will you guarantee the safety of all users of the makerspace ? What safety, emergency and first aid equipment is needed? How will health and safety rules and procedures be developed, communicated and enforced?

Teachers and teaching

- What will be the impact on teachers' workloads? *In many schools planning and development activities are carried out outside of school hours and depend upon the goodwill of teachers. Fernando Casimiro school in Portugal responded to this by "redefining the way the teachers' schedule is organised, allowing them to have more time to collaborate and design activities".*
- How will you prepare teachers for the challenge of simultaneously managing very heterogeneous groups of students working on diverse projects?
- What training and support will teachers need and who will plan and provide this? *Teachers will need to learn how to use specific tools, design student centred learning activities around their use and develop effective assessment strategies. Many teachers will require pedagogical as well as technical support.*
- How will teachers document and share ideas and lesson plans they develop?
- Who will be responsible for researching availability of teaching resources and acquiring these for the school?
- How will students' work in the makerspace be assessed?
- How do you convince teachers who do not want to teach in a different way? *This may include good teachers who achieve excellent results and may argue "if it works why change?"*

Spreading the word

- How will you expand use of the makerspace beyond enthusiastic early adopter teachers? *It takes time and effort to get all teachers trained and confident enough to be able to plan and facilitate activities themselves.*
- How will you disseminate good practice and lessons learned to all teachers in the school? *Initially it may be easy to share within a small group of innovative teachers, but expanding dissemination to all teachers may be more difficult when a school is busy with routine work.*
- Should you publicise your makerspace and its impact on the teaching and learning in the school? *This may be necessary for sustainability especially if you wish to attract partners. Your school could also benefit from networking or collaborating with other educational institutions including sharing ideas and good practice.*
- If your publicity is very successful, attracts media attention and other schools want to visit who will be responsible for communication and hosting visitors? Will this be an official part of a member of staff's role?

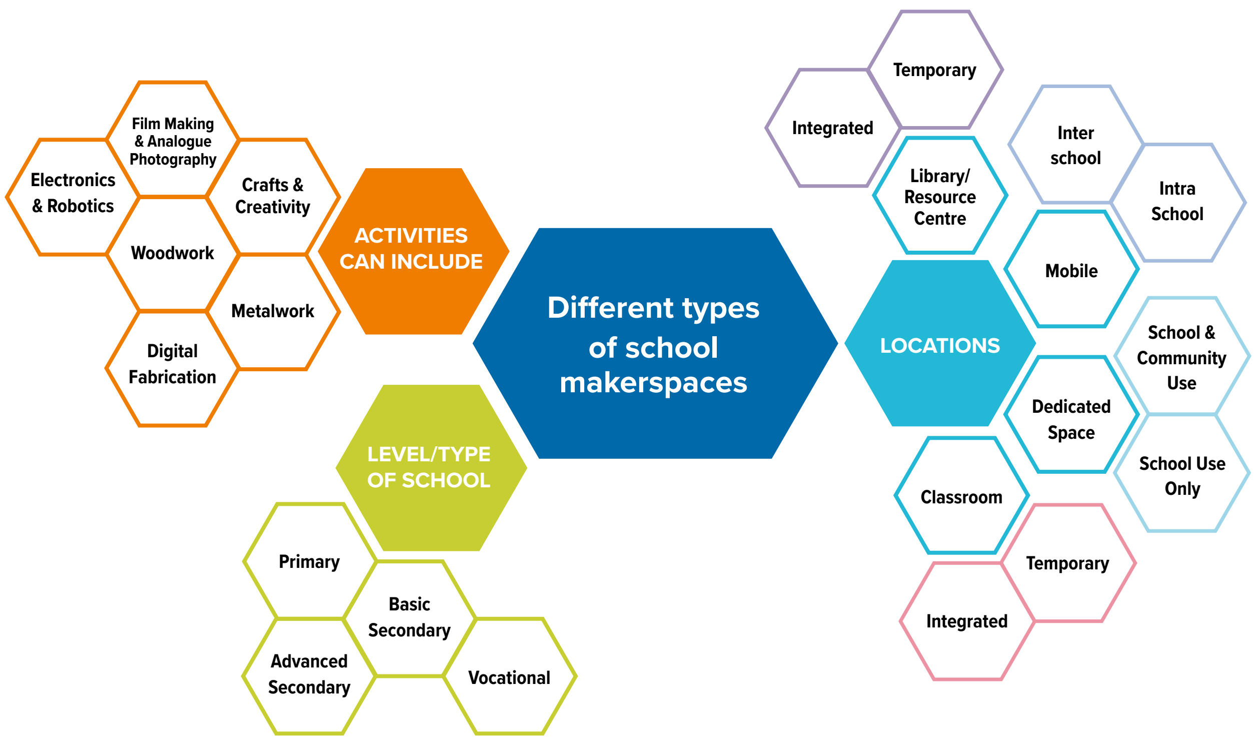
Part Two

Planning and Creating a school makerspace and makerspace toolkits

1. Types of makerspaces

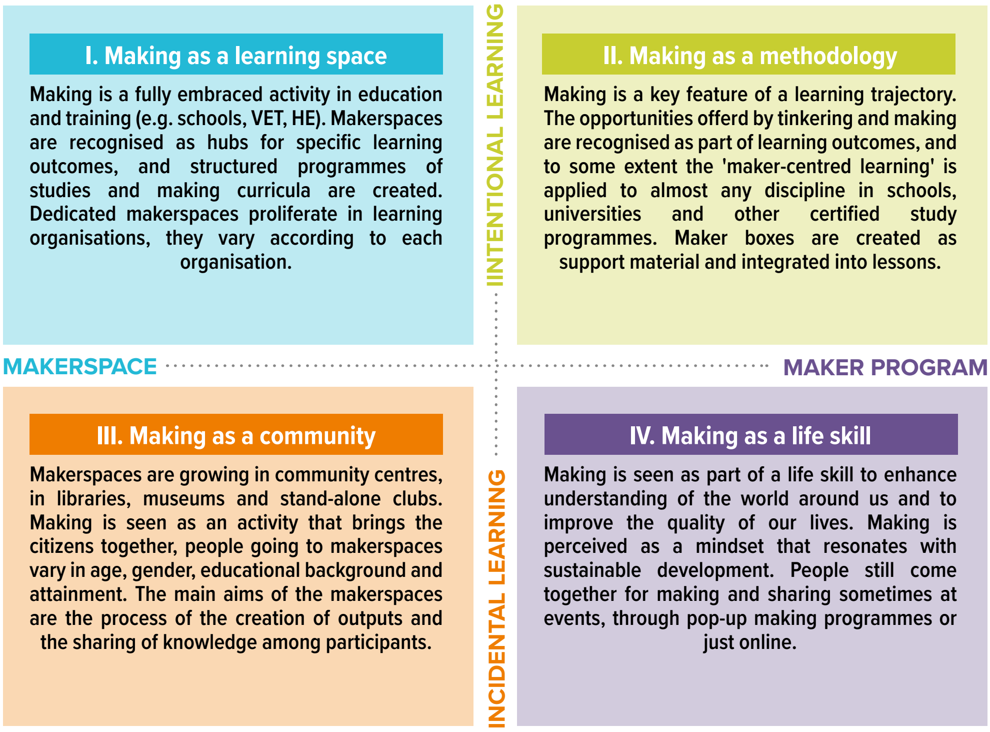
In considering what type of makerspace you can build, you need to be aware that there is not a single one-size-fits-all model for schools. There is a range of school makerspaces and they vary according to the:

- Level and type of school
- Number of students and teachers
- Size and nature of the school building(s)
- Funding available
- Culture of the school
- Interests and skills of school leaders and teachers
- Drivers for, and aims of, setting up the makerspace
- Desired focus for activities within the makerspace
- Support available from, and involvement of, industry partners and/or community makers



Attributes defining different types of makerspaces

Researchers have suggested[19] that there are four contexts for makerspace activities in education and training. These are defined partly by: whether learning is a deliberate or incidental outcome of the making activities undertaken. They are also defined by whether the makerspace is a makerspace, i.e. "*a physical space with a range of fabrication tools devoted for making*", or a maker programme, i.e. "*composed of making activities that are carried out in an ad-hoc environment using a mobile cart or a 'pop up' kit, for example*".



Vuorikari et al's four contexts for makerspaces activities in education and training

School makerspaces may correspond to the top left hand corner of Vuorikari et al's diagram, "making as a learning space", or the top right hand corner, "making as a methodology" if a makerspace is temporary or mobile. Dr Edvard Benes Elementary School, Praha - Čakovice, in the Czech Republic is an example of a school where, in addition to the permanent makerspace, teachers can take some of the equipment and move it easily into other places or classrooms, thereby effective creating a mobile makerspace.

In some cases, a school makerspace may also be open to people in their local area and students and teachers may be part of a local community of makers. In these cases the people who are not students or teachers may be most interested in making as a leisure or social activity and learning is incidental; therefore this corresponds to the lower quadrants of the Vuorikari diagram. Examples of this are the makerspace in HTL-Hollabrunn school in Austria, which has recently started opening to the outside community, including parents, friends and makers outside of school hours, and IC Lucio Fontana in Italy which was set up in partnership with a makers association.

2. Planning for a makerspace in your school

2.1 What do you want to achieve?

Consideration and discussion of what you want to achieve is the starting point for planning any new project in a school. In the case of makerspaces this will lead to decisions about the required focus, nature and location of the space.

19 VUORIKARI R, FERRARI A, and PUNIE Y, "Makerspaces for Education and Training: Exploring future implications for Europe", Publications Office of the European Union, 2019, link: http://publications.jrc.ec.europa.eu/repository/handle/JRC117481

At Scoil Íde, the Irish primary school described in one of the case studies, a teacher says that "*The development of discrete digital technologies skills, such as coding with micro:bits, and the use of Java script and Scratch are a key component and an aim of the school, in line with their digital learning plans*". Therefore, the makerspace this school created has a strong focus on electronics.

A technology teacher, who is also the school's Digital Manager, at IC Lucio Fontana in Italy visited and used some makerspaces and says she was "*spellbound by their sharing and creative environment"* that she felt *"could fit perfectly into the school*". The School Director, agreed that and observed that "*the school was already oriented towards developing creativity, so it was quite natural for us to build a makerspace*".

Another case study focuses on HTL-Hollabrunn school in Austria, which is a technical school for students aged between 15 and 19. One of the things the principal of HTL-Hollabrunn wanted to achieve was *"to enable students and teachers in HTL-Hollabrunn and local partner schools, as well as other interested external people, to participate in creative, project based, real life learning through making".* Therefore, planning and building of the school's makerspace needed to include enabling access to, and use of, the space by external people.

The Base 1 makerspace, which is shared by several schools and a youth support centre in Luxembourg, has as part of its remit a focus on preparation for work including providing workshops at professional as well as introductory and intermediate levels.

Interviewees at all case study schools were asked about their original motivation which led to the desire to set up a makerspace in their school, and about what they wanted to achieve.

In some cases, there were very specific circumstances within the school that suggested a makerspace was needed, or that prompted the idea:

- At a school in Portugal the success of a robotics club led to both the integration of robotics into the curriculum and the idea of setting up of a makerspace.
- In Switzerland, a school was due to start extensive renovation work on the school's building which involved clearing the library and this prompted consideration of using the space in a different way.

All of the case study interviewees cited several reasons and aims for creating makerspaces. Some were related to specific aims of the school or national educational aims, such as:

- To recruit more students and to make technical education more attractive.
- To support the school's aim of reflecting and integrating digital innovation trends.
- To promote 21st century learning.
- To incorporate more modern learning methods into the primary classroom.
- To improve students' digital literacy and computational thinking.
- To encourage digital citizenship, emotional digital intelligence and digital creativity.
- To incorporate creative elements, including Music and Visual Arts with STEM subjects (the STEAM agenda).

In Italy in 2016, as part of the National Digital School Plan, the Ministry of Education issued an invitation to tender for schools to apply for funding to build "atelier creativi" (creative workshops). These are workshops in which students use different tools and use their acquired knowledge to create real or virtual objects. The availability of this funding encouraged and enabled IC Lucio Fontana and the Second Comprehensive Institute Montessori-Bilotta to build makerspaces.

Some aims were generic, including:

- To encourage problem solving using logic.
- To encourage collaboration.
- To make learning more inclusive.
- To explore different ways of learning and teaching.

Some were focused on the **teachers and approaches to teaching**:

- To support and promote a constructivist approach to learning.
- To improve active methodologies and experimental activities.
- To support inquiry-based learning.
- To increase teachers' collaboration.
- To develop and test scenarios for effective teaching practice in a makerspace.
- To connect textbooks to practical scenarios and real life, to create more meaningful learning experiences.
- To increase inter-disciplinary working and build bridges between different subjects.

Some were about **students benefiting from the specific opportunities offered by makerspaces**:

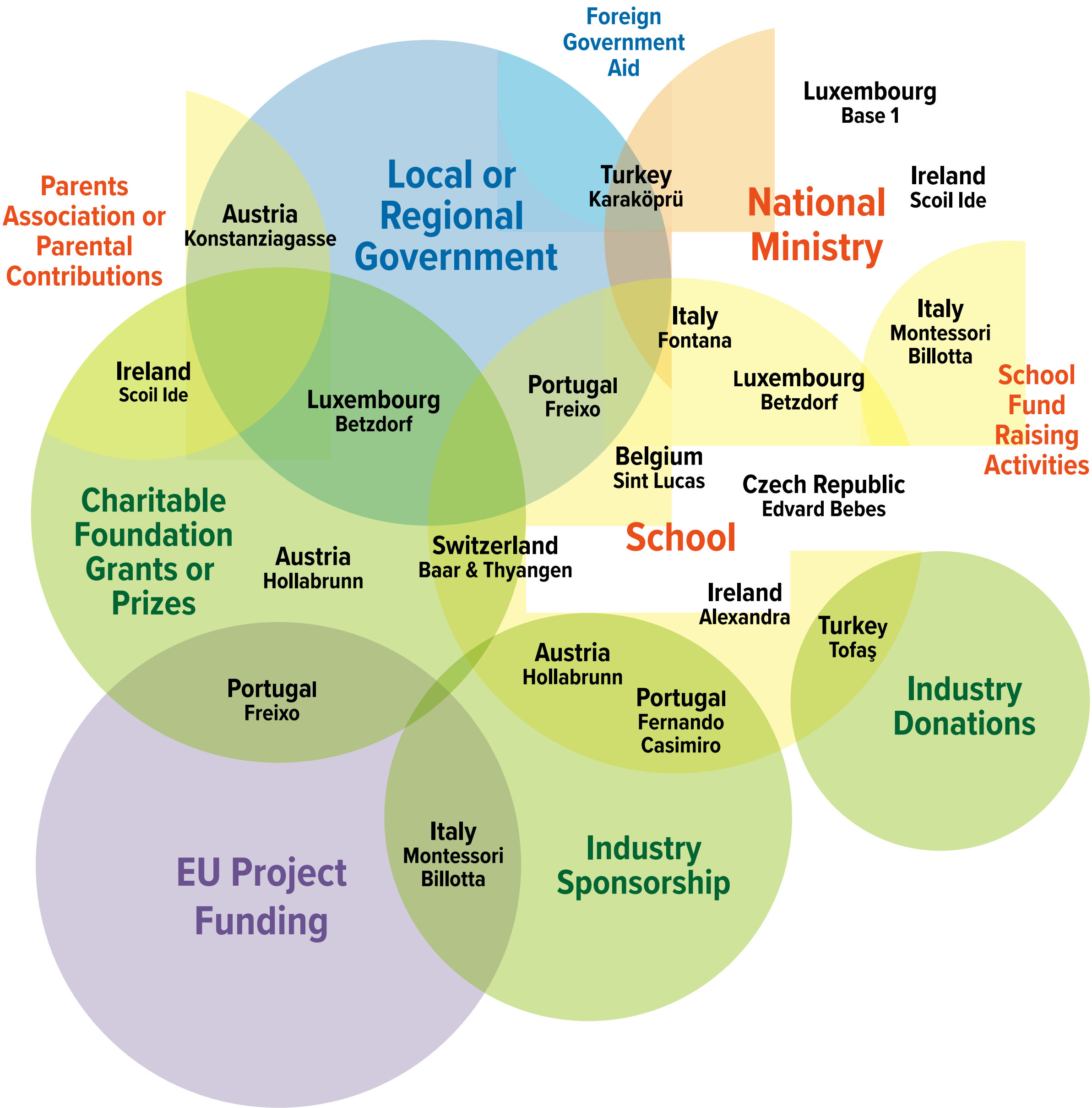
- To create a place where students can express freely their creativity.
- To develop students skills and give them freedom and opportunity to develop their own projects.
- To develop skills such as working together in teams, problem solving, computational thinking, communicating across the curriculum and bringing learning to life.

Some schools were motivated by **preparing students for futures in employment and society**:

- To prepare students for the pursuit of studies in areas facilitated by access to the latest technologies that are important for their future lives and employment.
- To increase the number and variety of career paths available to students.
- To direct individual students towards the best careers for them.
- To make technical education more attractive, especially for girls.
- To promote the ethical use of technology by students.
- To help pupils become creators rather than just consumers of technology.

2.2 Funding and the cost of setting up a makerspace

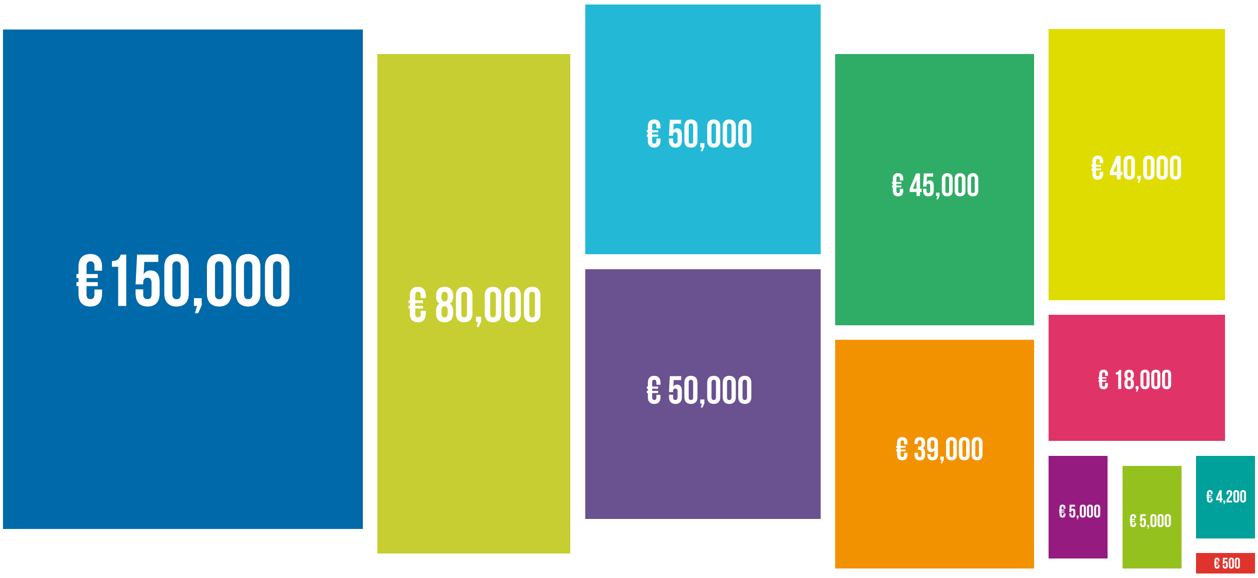
When setting up a large, permanent makerspace the initial costs, which may include structural work, can be substantial. Some machinery and equipment for makerspaces can also be expensive. Funding for this may come from European projects, national initiatives, local authorities or corporate sponsorship. Often the necessary funds are obtained in several tranches by accessing both public and private funding. In this case, it is advisable to create a design which includes a basic initial configuration of the makerspace with the possibility of expanding it later, dependent upon the funding available. Many of the case study schools accessed several different sources of funding to initiate, or continue development and operation of, their makerspaces.



Funding sources for case study schools' makerspaces

In many cases, schools have controlled set up costs by volunteer teachers and/or parents carrying out some refurbishing and decorating work themselves. This is one of the reasons why some schools find it difficult to say accurately how much their makerspaces cost to set up. The other reasons are mixed funding sources, the donation of equipment and materials and the ability to use equipment funded by other projects. It is also clear that the cost varies greatly from school to school dependent upon the size and type of makerspace created (see Part 2, Section 1). Where the case study schools have provided estimates they are very different.

It may be helpful to know that the median set-up cost, across all case studies which provided an estimate, was found to be approximately 40,000 euros. Some schools were able to spend more as the funding was available. Others spent less, sometimes much less, where little funding was available or where existing facilities and equipment could be used and/or the makerspace is a small occasional or mobile one.



The wide variation in the cost of setting up makerspaces

2.3 Location and integration

The location of a school makerspace needs to be carefully planned, including consideration of how it can be integrated into the school and, where appropriate, into the local community.

A school makerspace has the potential to become a place where activities carried out by students can create a bridge between the school and parents, siblings, friends, other schools and the local community and involve these people and organisations in a wide range of activities.

If the vision for the makerspace is for it to be integrated into the school, and to involve all teachers and all disciplines, the space created should be designed so that it does not look like an exclusively scientific or technical environment.

Another important consideration is the centrality of the makerspace. Where the architectural structure of the school allows, it is desirable that the space is in a highly visible position and easily accessible by as many classes as possible. It can help if the makerspace is set up close to the school library. At Baar school in Switzerland, the makerspace has a glass wall so that passing students can see what is happening inside and may be motivated to come in.

Integration into the school is helped by making teachers aware of the makerspace and how it is being used and by suggesting ideas for student projects. Suggestions for projects are useful in schools where makerspace use is not compulsory or closely linked to the curriculum. In this situation it may be the makerspace manager who makes these suggestions.

2.4 Accessibility and inclusion

When planning and designing your makerspace it is important to ensure that the opportunities it creates are not only accessible by a limited range of users.

At the very least, care should be taken to enable easy access for people with limited mobility, e.g. wheelchair users, by installing wide doorways and ramps. The DO-IT (Disabilities, Opportunities, Internetworking, and Technology) Center at the University of Washington in the USA encourages builders of makerspaces to "*apply principles of universal design to ensure the spaces, tools, and community are accessible to as many individuals as possible*" and explains that "*universal design encourages the design of space, products, and processes not just for the average user, but for people with a broad range of abilities, ages, reading levels, learning styles, languages, cultures, and other characteristics*".

They also advocate the use of participatory design *where individuals from diverse backgrounds bring their unique experiences and perspectives to the design process.* DO-IT have published "Making a Makerspace? Guidelines for Accessibility and Universal Design"[20] which provides more detailed advice.

See Part 1, Section 5.2. "Supporting and scaffolding students" for a discussion of the need to take care when introducing students with learning disabilities or special educational needs to makerspaces. Schools should try to include as many students as possible by providing appropriate support and scaffolding.

Inclusion should also include consideration of gender, as a variety of social pressures and circumstances can result in fewer women than men participating in STEM activities. Schools should ensure that makerspaces are welcoming environments for female students and seek to recruit female teachers or makers who can act as role models and mentors.

2.5 Organisation and management

The way in which you organise and manage your makerspace, as well as the number and type of staff you will need to involve, depends upon a number of factors including:

- The size of the school.
- The size and location of the makerspace.
- Whether the makerspace is in a permanent location, set up only at certain times or mobile.
- The type of machinery and tools used in the makerspace
- Whether or not the makerspace is used by external people.

School staff managing and supporting users of a school makerspace are likely to include teachers, ICT Co-ordinators, technicians and librarians or resource centre managers. In a large school several staff may share the role but in a small school managing the makerspace is likely to be just part of one member of staff's job.

In some cases, schools have formed an external association, or are collaborating with an external company, who provide people to manage, or help manage, the makerspace. This help may include providing assistance to teachers, during both curricular and extracurricular hours. The staff of the association or company may also take care of the maintenance and management of the equipment. These staff need to have experience of the maker culture and the organisation might be a Fab Lab, a not-for-profit association of makers, or an association of parents formed specifically for this purpose.

The makerspace in Betzdorf in Luxembourg is a collaborative project involving Betzdorf Primary School and Maison Relais, a local day care centre providing services to the community including people with disabilities. A teacher from the school is the "spacekeeper" during the school day and an educator from Maison Relais is the spacekeeper outside of school hours. The two spacekeepers co-operate and share ideas and good practice. This is helped by an arrangement under which the centre educator helps with organising activities in the makerspace within school hours every two weeks and the teacher works inside Maison Relais during the school's lunch time.

In Italy, IC Lucio Fontana have recruited two manager/makers through an external call to manage their makerspace. They support and organise training courses for its users, which include students and external people, during the day and in the evening. Whilst at the Montessori-Bilotta school a group of enthusiastic parents and teachers formed an Association which has provided technical advice to the school, prepared a machine purchase plan, will be responsible for maintenance and plans technical training for teachers. There is also a teacher who manages the timetable and a janitor who has been trained to help the teacher and maintain the space.

20 https://www.washington.edu/doit/sites/default/files/atoms/files/Making_a_Makerspace_8_03_15.pdf

At Freixo school in Portugal, the teachers responsible for the day to day operation of the make space are those who have experience in the areas of robotics, informatics and technology. There is also a manager responsible for the makerspace room and the acquisition and maintenance of equipment. In addition, the school has a partner organisation called Weproductise who provide support for the makerspace together with a team from within the school. The team includes ex-students who continue to use the makerspace, collaborate in activities and help with technical support.

The makerspace at Scoil Íde in Ireland is not in a permanent location. The makerspace materials are stored in a classroom and moved on as trolley to other classrooms which are then reconfigured to become a temporary makerspaces. All materials are returned to the base classroom when not in use in other rooms. Two teachers work as a team to plan the activities in the makerspace, including identifying and adapting suitable lessons that map to the curriculum, purchasing and management of makerspace kit, working with external partners and experts, and reaching out to parents in industry to bring in outside expertise. They upskill themselves on an ongoing basis as well as supporting other teachers.

The makerspace at Baar school in Switzerland is also not permanently available. The space is set up as a makerspace on Monday after school and on Wednesday afternoons (when there are no lessons). There are also teacher training workshops in the makerspace. The space works as a general area of the media library for the rest of the time. The manager of the makerspace is also the manager of media library in which it is located. She chooses the equipment and materials, organises workshops and trains the teachers. She also installs and maintains tools with the help of the school's IT team.

At Tofaş Science High School in Turkey the school involves students in the management of the makerspace. In every group one student is designated as the coordinator. This student looks after the room key and is responsible for ensuring the space is left clean and tidy when the group leaves. This encourages students to take responsibility for using the space appropriately. The makerspace manager says the school aims for students to "*create an ecosystem among themselves*" and "*we give great importance to peer learning, upper grade students train lower grade students and teachers act as a guide. Therefore, when teachers move to different schools, it is not as important as it is in traditional teaching. Thus students work in a more sustainable way*".

In addition to technical skills you will wish to ensure that staff involved in managing makerspaces are:

- Able to work effectively and constructively with the school's students.
- Able to work alongside and support teachers.
- Have the ability to design training, including courses and workshops, for school and external users.

Providing training for external users can generate income which could contribute to the sustainability of the makerspace.

Research by INDIRE has found that the way in which a school's makerspace is regulated affects the way students interact with teachers, classmates and equipment when pursuing their innovation projects. When students are free to interact with the environment, such as to move furniture, draw on (drawable) walls and independently access equipment, they have the opportunity to be creative without limits. On the contrary, if a makerspace has too many restrictions on the use of machinery, tools and materials and the organisation of space is too rigid, it is unlikely to achieve its aims.

Nevertheless, flexibility and freedom of course does not mean health and safety (see Part 2, Section 2.6) should be ignored and this, as well as students ease of use of the space, can be assisted by careful consideration and planning of ergonomics (see Part 2, Section 3.2.2.).

2.6 Health and safety

Policies and rules

Your school may have health and safety policies relating to the use of existing science labs and workshops. Setting up a makerspace is likely to increase the number and variety of machines, tools and materials that students and staff will be interacting with and, therefore, existing policies should be reviewed. Advice on health and safety regulations and precautions may be available from local, regional or national government experts, officials or departments. Industry partners may also have experts who can provide useful advice to schools.

Most of the case study schools mentioned health and safety policies or rules and how the students are made aware of these, for example:

- In Turkey students using the Karaköprü makerspace are informed, or reminded, about safety rules before every course. Whilst, at Tofaş Science High School, students attend a one-week orientation course which teaches them about occupational safety, introduces the equipment and explains how it is correctly used.
- Alexandra College Junior School in Ireland and the Base 1 makerspace in Luxembourg have registration forms or contracts that students and parents sign, which detail the rules and regulations of using the space including health and safety rules.
- At Silberberg Primary School in Switzerland, each class works on two maker projects, one of which is focussed on acquiring the skills students need and learning about the health and safety regulations in the makerspace.

Konstanziagasse school in Austria mentioned that the Future Learning Lab in Vienna is developing a health and safety policy and the school will adopt this.

More detailed advice on Health and Safety in makerspaces can be found in The Makerspace Playbook[21] from page 13.

Properly installed and maintained equipment that conforms to safety standards

In makerspaces in schools within European Union countries, all machines purchased must be CE certified[22] and installed according to the manufacturer's instructions. This avoids many potential safety problems as CE certification requirements prevent the sale and installation of potentially dangerous machinery.

However, careful and continuing consideration of safety is still required. For example, it is important to ensure that:

- Appropriate routine cleaning and maintenance of machinery is carried out.
- Safety guards fitted to machines are always used and never removed.
- Emergency cut-off switches are appropriately located to enable quick and easy access.
- Training is given to all staff and students who will be using machinery.

The Austrian case study schools emphasised that they ensure that "*All tools and devices [used in their makerspaces] are of high quality and conform to safety standards*".

21 https://makered.org/wp-content/uploads/2014/09/Makerspace-Playbook-Feb-2013.pdf

22 CE marking proves that a product has been assessed and meets EU safety, health and environmental protection requirements. It is valid for products manufactured both inside and outside the EEA, that are then marketed inside the EEA.

One of the Italian case study schools also mentioned that they have “a school safety manager, who regularly inspects the makerspace in order to *verify that all the machines still comply with the safety standards*”.

At HTL-Hollabrunn school in Austria additional safety features for some tools are being built by senior students e.g. a cover for the CNC machine made from acrylic glass with safety sensors, so if someone opens the cover the machine stops immediately.

Protective clothing and maintaining a clean, tidy and safe environment

Students working in makerspaces must be provided with, and wear, protective clothing when they are undertaking potentially hazardous tasks, such as gloves, masks, eye protection glasses and ear protectors.

In a makerspace many types of materials are handled and processed (such as wood, paper, cardboard, metals, plastics, paint, oil and glue). Many of these materials produce waste when cut that can be harmful (such as waste from cutting metal can damage hands and dust from machining or sanding MDF board[23] can cause respiratory problems) or may be a fire risk if allowed to accumulate; and spilled liquids create slip hazards.

At Scoil Íde primary school in Ireland, where the makerspace is set up when required:

“*When a classroom is configured for use as a makerspace, in the evening before it is to be used, care is taken to allow space for pupils to move easily from station to station. Then, before it is used, the classroom is completely cleared of school bags and other items which could cause students to trip over*” and “*the students are made fully aware of health and safety and the procedures for clearing the classrooms*”.

With permanent makerspaces health and safety should be planed for when the layout of the space is designed e.g. locating potentially dangerous machinery in a separate area from more general activities.

Where there are potential risks to the health and safety of users of makerspaces it is necessary for there to be adult supervision of students. Also staff and students need to be made aware of risks and students should be introduced to a culture of safety and cleanliness, including making them responsible for age-appropriate related tasks, behaviours and operations. Even young students, if properly supervised by teachers and technicians, can quickly learn to comply with safety regulations and to safely and correctly use some tools and machines.

Fire safety and first aid

Appropriate, and regularly serviced, fire extinguishing equipment needs to be available in a makerspace. These should be highly visible, easily accessible and located near to areas or machines identified as presenting a fire risk. It is also important to ensure that a first aid kit is available and easily accessible, that its contents are regularly checked and replaced as necessary and that staff are given first aid training.

23 Medium-density fibreboard (MDF) is an engineered wood product made by breaking down hardwood or softwood residuals into wood fibres.

Security arrangements where expensive equipment is used

When asked about health and safety several case study schools also commented on security arrangements which were felt to be necessary in view of the equipment installed in their makerspaces; these included burglar alarms, video surveillance systems and in one case security guards.

2.7 Risk Management

Any new initiative introduced in a school, especially one that involves significant adaption of, or addition to, a school's teaching and learning spaces, involves some degree of risk.

In the case of makerspaces there are some potential health and safety risks associated with the use of tools, machinery and materials. Part 2, Section 2.6 "Health and safety" explores some of these and necessary strategies to avoid, or deal with, accidents.

However, perhaps the greatest risk is that a school creates a makerspace but is not able to exploit it to gain the maximum benefit for the students or, in the worst case scenario, the makerspace is not used. This may be the result of one or more of the following:

- Insufficient training for teachers, resulting in their lacking the competence or confidence to operate effectively in this type of environment.
- Lack of personnel with sufficient experience in using the equipment.
- Lack of technical support during lessons, leaving teachers to try to solve technical problems alone.
- Absence of a maintenance and replacement programme, resulting in equipment becoming unusable or obsolete.
- Lack of, or insufficient, on-going funding after the initial set of the makerspace, which is required for sustainability by paying for continuation of, for example, machine maintenance, training, technical support and materials (see Part 2, Section 5 for examples of sustainability planning).

Risk planning and risk management are recommended, especially when a school is planning to set up a large, complex and expensive makerspace. School leaders and ICT coordinators may be familiar with risk management processes. These typically involve drawing up and regularly reviewing a list of risks, sometimes called a risk register. A risk register lists anticipated risks, how serious they are and how likely they are to occur. It also records who is responsible for managing the risks and plans for how they will be avoided or mitigated.

2.8 Training and supporting teachers

Research by INDIRE suggests that:

- A key aim of staff development should be to provide teachers with the skills and confidence to design and deliver educational modules that exploit the potential of the makerspace.
- Motivated, competent teachers, who are aware that they are part of an evolving and growing community will help to ensure the initial and continuing success of a makerspace.

Professional development and support of teachers in case study schools

In most of the case study schools, training and professional development for teachers is a mix of formal and informal learning. Also teachers often learn from each other and, in some cases, from or with their students.

An effective model for staff development is some initial formal training courses, often delivered by the makerspace manager or coordinator sometimes in collaboration with external organisations, followed by teachers further developing their knowledge and skills through:

- Inquiry based learning and learning by doing, sometimes mentored by makerspace managers.
- Collaborative learning, using online resources and reading manuals.
- Learning from other teachers, or skilled students, who act as buddies for teachers new to making.

The type of training required depends, to some extent, how the makerspace is used. In some schools training for teachers is focused on a specific skill set that the teachers can then transfer by means of specific projects. However, where students are free to choose what they will make, with which equipment and materials, many different skills may be needed and therefore more training will also be required.

Schools often organise short courses or workshops for teachers focussed on specific technical topics or technologies e.g. robotics, Scratch coding, 3D printing, laser cutters, microcontroller boards, etc. However, as experienced makerspace teachers at Scoil Íde school emphasise to their colleagues, teachers do not need to become technical experts but they do need to:

- Understand how to approach STEM and makerspace lessons.
- Facilitate learning instead of providing students with answers.
- Encourage students to think like engineers.
- Focus on how science is part of everyday life.
- Develop experimental approaches to learning.

At Tofaş Science High School, courses for teachers include a requirement to assign project work for their students to carry out in the makerspace.

At the Betzdorf makerspace in Luxembourg, the teacher who is the spacekeeper provides advice, support and mentoring. He also supplies teachers with materials and "ready-to-use" activities so that "*even if they have had no previous experience of making they can lead class activities on their own*".

As teachers use makerspaces, they increase their own skills and develop effective strategies for supporting students.

It is important that this knowledge and good practice is shared throughout the school. This not only benefits other teachers, but also helps to ensure sustainability by reducing the school's dependence on a small number of early adopters.

Some case study schools, including Dr Edvard Benes school, Praha - Čakovice, in the Czech Republic also share knowledge and good practice by running seminars in their makerspaces for teachers from other schools.

Also at the Czech case study school, teachers are encouraged to join an informal group focused on innovative teaching methods, which may or may not focus on makerspace activities. The group, which currently includes approximately 15 of the school's 80 teachers, meets once a month to exchange their ideas and good practice and to prepare training for each other and for other teachers within the school.

The School Director at IC Lucio Fontana in Italy described how use of the makerspace increased as more teachers became competent users of it and how this encouraged more teachers to get involved.

She said "*the more teachers become expert, the more often students can use the makerspace. The more the students use the makerspace the more the space becomes interesting for parents and for new teachers who are intrigued and therefore use the makerspace*".

Training in collaboration with external organisations

Training for teachers in the use of specific technologies may be provided by the companies that supply, or donate, the equipment. Schools may also work with higher education institutions which may provide, or collaborate in the delivery of, training for teachers.

In the two Austrian case study schools, some training was carried out in collaboration with the University of Education Lower Austria. In the case of HTL-Hollabrunn school, after the initial training, there were monthly visits to the school by external teaching students working on projects. HTL-Hollabrunn school also works with a start-up company which provides workshops for both VET students aged 14 to 19 and their teachers. At Konstaziagasse school, some training was also provided by experts from the Future Learning Lab at University College of Teacher Education in Vienna.

At Sint Lucas school in Belgium, there is a monthly training session in the makerspace run by CoderDojo, an organisation that teaches young people to programme using robots and computers, and during the Easter holiday there is also a Robotcamp for 6th grade students.

Silberberg Primary school in Switzerland works closely with researchers from their local University of Teacher Education and these researchers also function as trainers and as makers that support the students.

Fernando Casimiro school in Portugal is frequently visited by trainers from the Ministry of Education who help to deliver special courses for teachers, and teachers from Scoil Íde school in Ireland have participated in 'Teach Meets' at the local Education Centre in Limerick. This Education Centre is one of a network of 21 full-time and 9 part-time Education Centres located throughout Ireland, funded by the Department of Education and Skills to deliver national and local programmes of teacher professional development.

Teachers working at the Karaköprü makerspace, which is shared by two schools in Turkey, are able to attend training courses organised by external experts thanks to financial support from Karacadağ Development Agency (one of ten regional development agencies in Turkey, set up to "develop an institutional mechanism to implement the regional development policies at local level"). They also participate in training organised by EU-funded projects.

Base 1 makerspace in Luxembourg employs external freelance coaches who are used to motivate students by providing interesting workshops, giving demonstrations and organising hands-on activities. These external coaches also act as mentors. Training sessions are also organised by IFEN, a national training provider for educators. These sessions are related to specific curriculum topics and provide teachers with ideas about alternative ways to engage their students in learning.

Irish teachers have commented that in addition to the knowledge and skills gained when learning from, and with, other organisations and institutions, it is good to feel part of a wider network. Within an individual school there may be only one or two teachers responsible for the makerspace and this can sometimes make them feel rather isolated.

Teacher engagement and encouragement

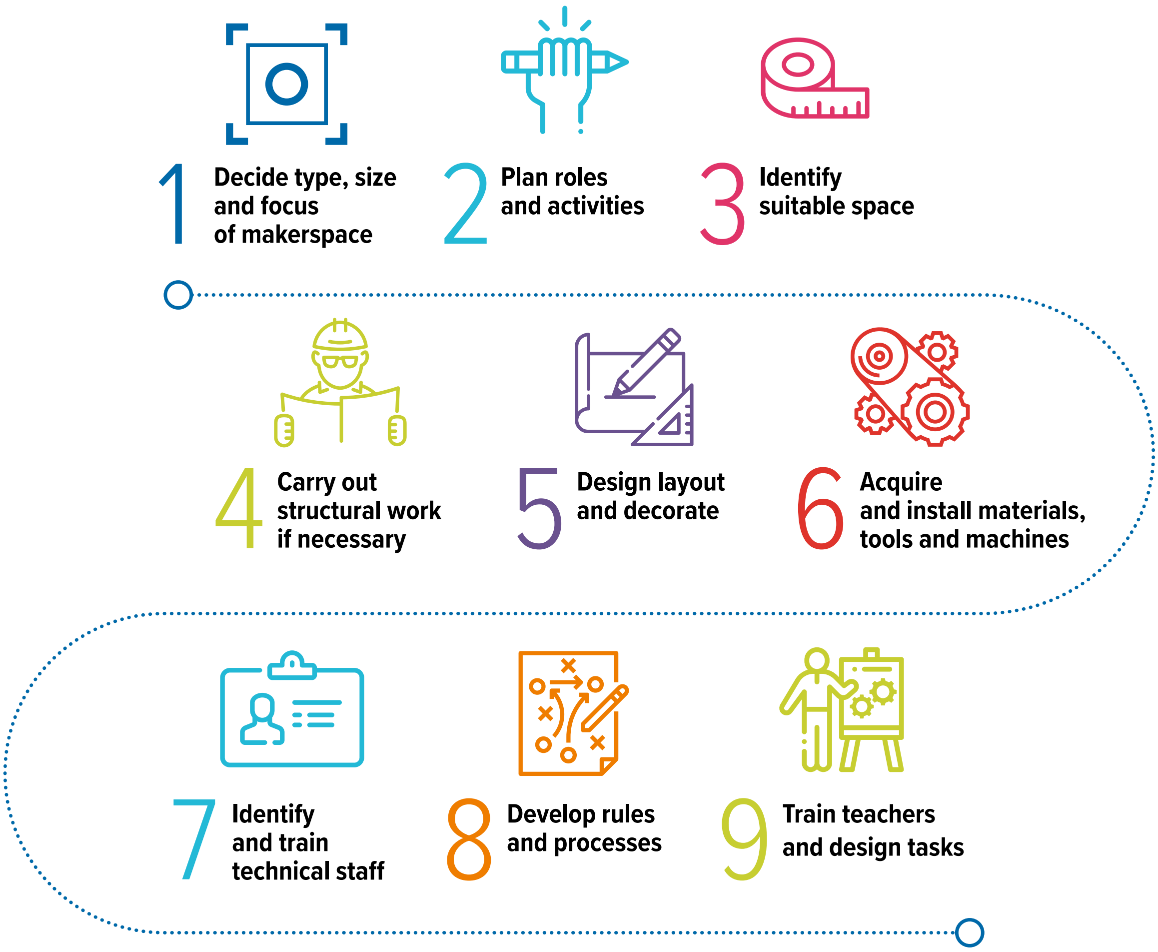
Any innovation in a school requires the support of the teachers if it is to succeed, and teachers are more likely to support something new if they feel involved in the decision making process when it is introduced. At IC Lucio Fontana in Italy the Digital Manager gave a presentation at a staff meeting explaining what the makerspace would be like and how it would be used for educational purposes. Then all the teachers voted on whether or not to proceed. They voted unanimously in favour of creating the makerspace.

In most schools a teacher, or the makerspace manager, is responsible for publicising the existence, use and achievements of the makerspace within the school and, often, to the outside world. Such publicity can help to encourage teachers to use the makerspace in schools where this is not a mandatory requirement. The makerspace manager at Baar school uses an Instagram account, a website and a blog to publicise activities and projects and also distributes a monthly news sheet to all of the school's staff.

3. Creating your makerspace

When creating a makerspace there are many practical considerations concerning physical assets. An early priority is finding an appropriate space within the school in which to locate the makerspace. Once a space is agreed upon it may be necessary to make structural adjustments to that area of the building, such as adding doors or windows, installing or removing partitions. After this, the space can be decorated and furniture, tools and any machinery can be acquired and installed.

Creating a makerspace also involves issues relating to personnel, their management, motivation and training, as well as the need to change attitudes and established practices. These aspects can only be addressed and resolved by careful planning of roles and activities.



Creating a makerspace step-by-step

3.1 Building considerations

Most makerspaces have been created within existing schools, the designers of which did not anticipate spaces of this kind. In some cases the school buildings may have been designed a century or more ago, but even relatively recent structures often are not ideally suited to activities of the type carried out in makerspaces.

School leaders and teachers therefore have to create makerspaces in spaces designed, and previously used, for other purposes. It is quite common to find makerspaces in basements or other peripheral areas of schools. Such environments often require structural and decorative changes. These changes may be undertaken by school staff, if they have the necessary skills, parent volunteers or external professionals.

3.2 Design, layout and decoration

3.2.1 Access

A makerspace must of course be accessible from inside the school. Students and teachers should be able to use this environment as they would any other space such as the library, workshops, classrooms or gymnasium.

A makerspace may also be shared with external organisations or individual makers outside of normal school hours. In this case, access needs to be enabled by having an additional external entrance separate from the usual school entrance. Where the makerspace does operate outside normal school hours, when school staff are not usually available, models of sustainable management are used that can include opening of the space by external personnel.

As a new makerspace is likely to contain expensive equipment and may have an external door for community access, schools should review their security measures to take into account these additional risks.

3.2.2 Ergonomics

Ergonomics has been described as aiming to "create safe comfortable and productive workspaces by bringing human abilities and limitations into the design of a workspace, including the individual's body size, strength, skill, speed, sensory abilities (vision, hearing), and even attitudes"[24].

In any makerspace it is necessary to create a safe, comfortable and versatile environment for students working individually and in groups. The working environment must be well organised and large enough to provide sufficient space for student makers to move safely around each other.

Students may need to work in groups, possibly large groups, on a product. In some cases, for instance building a robot, there may be more than one team, such as an electronics team and a mechanical team which must interact . The work of such teams involves a flow of people (and information) within the makerspace that must be regulated and facilitated by a well-organised space where the thematic areas are adjacent without hindering each other.

Typical activities in maker mode involve three phases: design, implementation and verification. These three activities are carried out in different ways and using tools which may not be close to each other. For example, if the goal is to print a part with a 3D printer, the maker must first draw the part on a computer using 3D drawing software, then go to the 3D printer and manage the printing steps. Finally, the result may be analysed, and improvements designed in a third area. Signposting is a key aspect in this context. The positions of all instruments, the basic rules of use and, of course, the safety precautions must be indicated.

3.2.3 Lighting

Specific lighting solutions may be required to ensure that students can carry out tasks efficiently and safely. It is necessary for makerspace users to be able to see clearly the tools and materials being used in all areas of the makerspace, at all times of the day and during all seasons of the year.

The possibility of involving an expert to study the most appropriate lighting solution should be considered. This may be the role of an appropriate industry partner. Key considerations include:

24 Dohrmann Consulting, www.ergonomics.com.au

- Lighting should be effective but not tiring for eyes
- Mixed systems with ambient light plus specific counter-top lighting are preferable
- It may be appropriate to illuminate specific areas of a larger environment, and not other areas that are not in use at the same time.

Providing articulated table lamps, that help users see well while they are performing delicate operations, and table magnifiers, with articulated arms, is very useful for all users of makerspaces and especially for any with sight problems (see Part Two Section 2.5 for information on accessibility and inclusion including maximising access for students with disabilities or learning difficulties).

3.2.4 Electricity

Particular attention must be paid to positioning electricity sockets around the room and to evaluate the planned strategy for supplying electricity in the context of the design and use of the makerspace. It may be advisable to create columns allowing cables to be lowered from the ceiling above each work area, to avoid obstructions in passageways. For the same reason, it is generally not recommended to use power extension adapters on the ground, which can be a trip hazard.

3.2.5 Floors and walls

Floor design, in terms of material used, strength, colour and patterning, is important.

In a makerspace there are likely to be more activities which could damage floors or cause them to become unsafe or difficult to clean, including use of glue, paint, oil, hot materials and sharp tools.

When heavy machinery, such as lathes, is to be installed in a makerspace the strength of the flooring must be checked, especially if the planned location for the makerspace is not on the ground floor.

When installing a new floor in a makerspace, it is advisable to create areas of different colours to highlight different making areas within the space. Grid floor structures are useful for organising working groups and younger children benefit from having lines they can use as a reference for “aligning”. Tracks on the floor can be used to direct and assign students to a specific areas or sections of the floor grid thus the flooring model, if well designed, can support the management of groups using the makerspace.

Throughout a makerspace different areas, dedicated to different types of work, can be characterised by coloured walls or furniture. Colours can help teachers and students to distinguish places dedicated to specific activities. However, too many colours can be distracting, and very bright colours may strain users’ eyesight.

3.2.6 Acoustics and noise

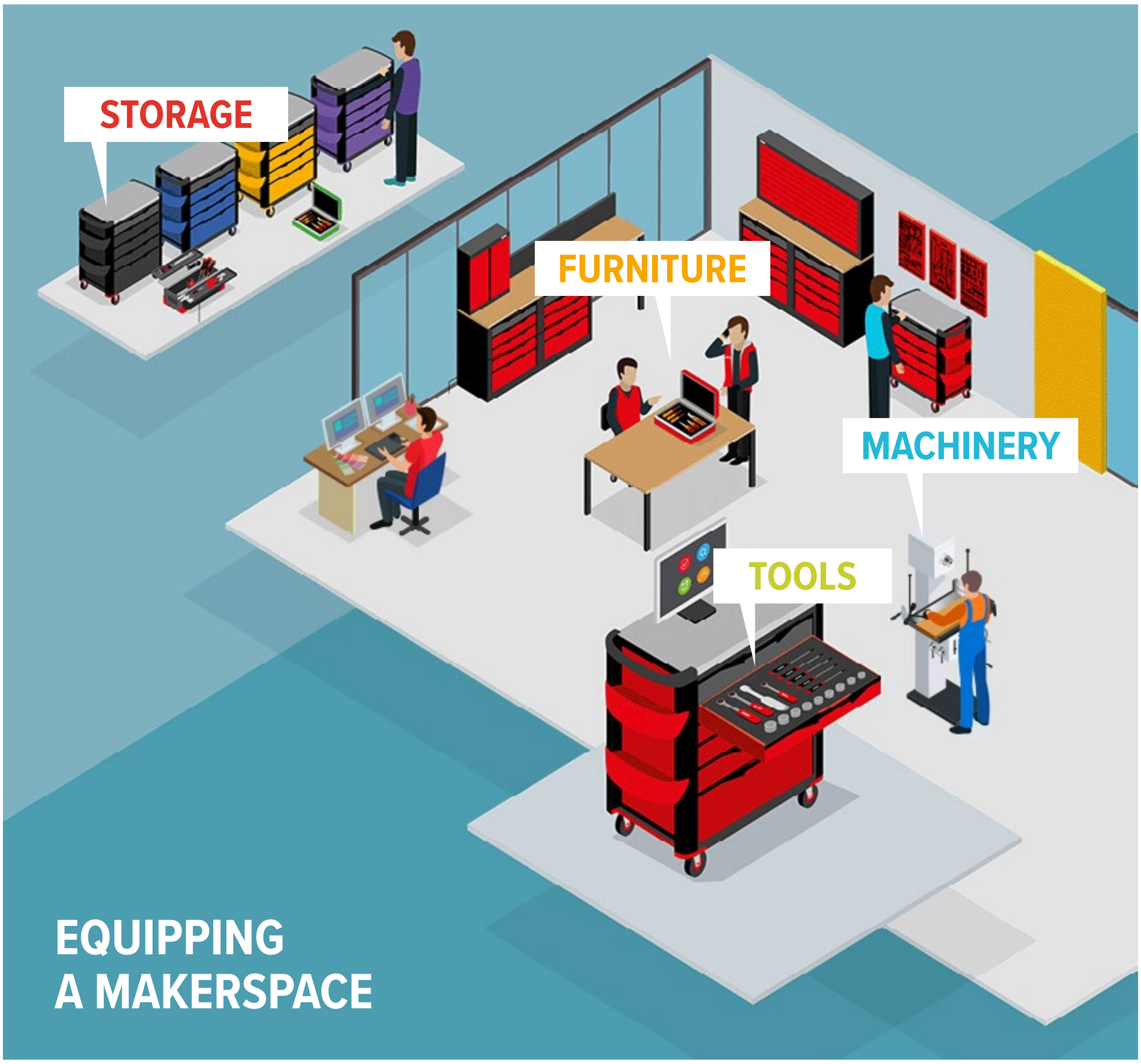
Makerspaces usually involve students and, if relevant, other makers working collaboratively; which can lead to higher noise levels than in standard classroom. Acoustics, and arrangements for reducing noise levels, should therefore be considered including appropriate ceiling tiles, wall and floor coverings. In large spaces, dividing screens that absorb sound can be used. Such screens can also be used to surround nosier machines which could otherwise be very distracting for users of the makerspace and adjacent rooms. Possible noise nuisance should be considered when choosing the location of the makerspace within the school building.

3.3 Equipping your makerspace

There is no universally applicable recipe for creating the perfect makerspace. To help schools choose the equipment that best suits their specific environment and requirements, it may be helpful to focus planning on four categories of equipment used to support making activities: Furniture, Storage, Machinery and Tools. A variety of materials will also need to be purchased or acquired to be used for making things either by hand or using machinery.

Several of the case study schools mentioned that they have started with a small amount of equipment and added to this when they could. Regarding deciding what equipment to buy, schools' ideas have come from:

- Attending fairs and conferences.
- Recommendations from teachers and IT staff in their school and other schools.
- Recommendations from members of various teachers' professional communities e.g. Google Edu Group and eTwinning.
- Recommendations from suppliers and sponsors.
- On-line research.



3.3.1 Furniture

A makerspace should be a welcoming, exploration-oriented space that inspires students' creativity and supports enthusiasm, experimentation and collaboration. Furniture and furnishings can help to achieve this. These should be informal and easily movable in order to create a flexible and accessible environment which encourages free movement of students. Expensive furnishing solutions are not necessary, the basic requirements are:

- Spatial organisation of tables and chairs that encourages collaborative work.
- Tables and chairs, which can be easily moved (such as light chairs or chairs with wheels).
- Open shelving for storage that facilitates visibility and accessibility of materials.
- Surfaces that are colourful and easy to clean and help to create a welcoming environment that fosters creativity.
- A soft area with carpets and creative seating solutions, such as bean bags, large cushions or foam blocks, may also be provided for thinking and discussion.

Many factors affect the choice of furniture, including:

- the budget available.
- what furniture and fittings can be built within the schools by staff, parents or students.
- the size of the space.
- the availability of resources.
- the activities planned.
- the pedagogical approaches to be used.

It is advisable to install modular reconfigurable furniture solutions, including chairs and tables of different heights (or adjustable) to accommodate students of different ages and abilities in a comfortable way. Wheels on tables and chairs must be able to be locked so that they do not move during activities and create unstable situations. Teachers at Primarschule Silberberg in Thayngen in Switzerland upgraded inexpensive wooden work benches by fitting wheels.

The surfaces of furniture students will be using, including benches and tables, need to be appropriate for the activities planned. Each activity involves certain types of tools or machinery that should be set up on suitable surfaces. Tables for computers should be typical desks whilst worktables for carpentry, mechanics and electronics should meet the specific needs of these activities. They should be robust and washable, but not so perfectly neat that users are afraid to work on them. Some activities have specific needs; robotics tables, for example, have a raised edge to prevent robots from falling to the ground as they move.

3.3.2 Storage

Makerspace environments generally use a considerable amount and variety of tools and materials and setting up even a small simple makerspace requires careful consideration of storage solutions.

This is to avoid clutter, to assist easy location of required tools and materials, and to ensure that potentially dangerous objects are not left unattended and are stored in a safe place when not in use.

Materials, tools and reference sources available in a makerspace should be visible, and easily available to students, so they are not inhibited from using and interacting with them. It is therefore preferable to have open and accessible shelves and other wall mounted solutions, rather than closed cabinets. It is also necessary to arrange adequate and appropriate storage for students' work-in-progress so that this is safely preserved until completion. Regarding the storage of sets of tablet computers, other mobile ICT devices and programmable robots, the type of storage should keep them secure and enable the IT coordinator or teacher to easily charge them and to install or update software. There are many charging cabinets available that support this.

3.3.3 Machinery

The amount, size and complexity of machinery in a makerspace will vary according to the requirements and funding of the school. Some machines will be quite small and fairly clean, such as small 3D printers or sewing machines. Others may be large and produce waste material that needs to be cleaned up and disposed of such as computer numerical control (CNC) machines, including grinders, lathes or milling machines. All machines need to be thoughtfully and appropriately located. Some may be freestanding on the ground, for example large 3D printers or laser cutters. Other machines must be placed on the benches or tables. It is always necessary to pay attention to the minimum safe distance between one machine and another and the position of the electrical sockets or ventilation, for instance.

3.3.4 Tools

There are no specific tools that define a space as a makerspace. A makerspace is defined by the maker philosophy and, in schools, by an approach to teaching and learning that emphasises inquiry, exploration, creativity and construction of both objects and knowledge.

Appropriate tools, equipment and materials need to be planned and made available. See Part 2, Section 4 for examples of toolkits that may be provided in a school makerspace. Also, and perhaps most importantly, schools need to consider the students, and how they will be encouraged and supported to use the opportunities for creativity afforded by the tools in the makerspace.

The equipment in a makerspace can be acquired gradually, starting from a basic supply made up of tools and resources already in the school plus specifically purchased, or donated, equipment. It is, however, essential that tools and machines in makerspaces are professional products and not toy tools but they also need to be appropriate for the age and abilities of the students using the space.

The makerspace manager at Baar school in Switzerland says "new tools become available all the time and time spent in research and testing is rarely wasted. Sometimes a school may buy, or plan to buy, something and then discover something similar which is more appropriate for their students or more cost effective".

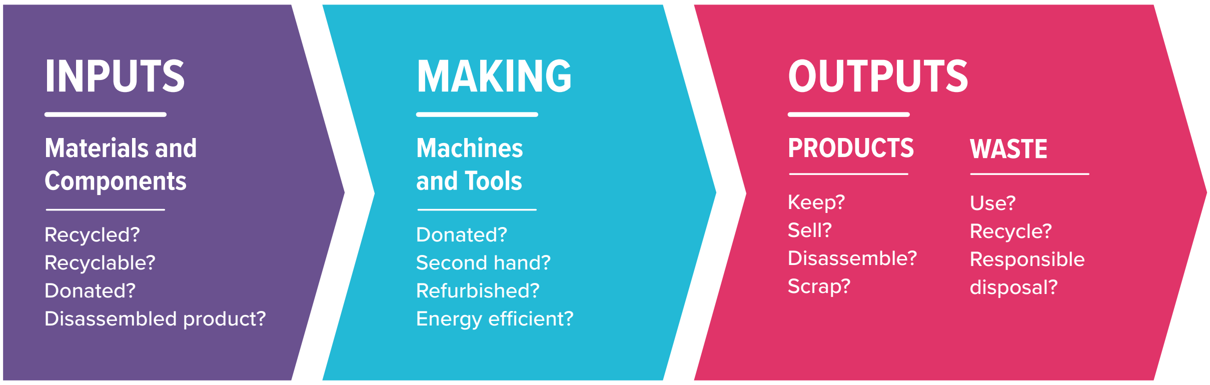
Training and support for the use of tools and machines must be provided in order for students to learn to use these correctly. Students should also be taught and encouraged to take responsibility for the equipment and materials they use and the ways in which they use these and the space in which they work. A makerspace should be a place where a culture of responsibility, and respect for people and equipment, is developed.

3.3.5 Materials

Even the most ordinary materials (such as cardboard and empty plastic bottles) can become intriguing and stimulating, depending on the way they are used. Materials that will need to be purchased for a makerspace include consumables for machines and activities such as. 3D printer reels, solder, electronic components, screws, nails, sewing thread and paint.

3.4 Recycling and environmental considerations

Part of the maker philosophy is the promotion of recycling and environmental sustainability.



Considering the environment throughout making processes

It is therefore desirable that some of the materials used in a makerspace are being recycled or can later be recycled.

Schools may be able to obtain much of the wood, metal, card and fabrics needed for makerspace projects from local community recycling centres, local businesses or students' families. Makerspaceforeducation.com advises teachers to ask students to bring unwanted items from home (including boxes, bags, cans and fabrics) to use to create "*Inventions with recycled materials*[25]" in the makerspace. They emphasise that this type of making is familiar territory for many teachers who may have "*built towers for third grade science, constructed geometric shapes with toothpicks and marshmallows in seventh grade math, or built a puppet theatre for Language Arts*" and can therefore be a good starting point for teachers who are new to makerspaces.

The tools and machines used to process materials, as well as furniture in the makerspace, can also include recycled, refurbished or donated items thus reducing both cost and environmental impact. Although when acquiring older second-hand machinery, schools should consider the energy efficiency of these. It is also important to be sure complex, powerful machines are really needed and to remember that "*many projects can be completed with a few hand tools, along with some simple power tools such as an electric drill, jigsaw, and circular saw*[26]".

Schools should consider carefully whether they need new products and kits specifically marketed for makerspaces and schools; in some cases, students may be able to make alternative components. For example Feride Bekçioğlu Secondary School in Turkey does not use purchased robotics kits, instead

25 http://www.makerspaceforeducation.com/inventions-with-recycled-materials.html#

26 St Hlubinka, M et al, 2013, "Makerspace playbook school edition", Maker Media

"*students and teachers make all the parts of the robots, some using the 3D printer and some using other materials e.g. wood*". It has been observed[27] that "*Sustainable development is not inherent to makerspaces. The maker movement presents an emerging market for suppliers of all sorts of consumer tools, materials, kits and activity. The ability to personalise rapidly the fabrication of objects … raises concerns about an intensification in the consumption of materials and objects … that are discarded just as rapidly as they are made*".

Environmental considerations include ensuring a responsible approach to waste management e.g.:

- Batteries, bulbs and other electronic waste should not be disposed of in the general refuse collection which may end up in landfill sites.
- Paints, oils and solvents need to be disposed of appropriately so that they will not cause pollution.
- Water soluble paints and brush cleaners should be used to reduce use of environmentally damaging chemicals.
- Where possible unwanted products should be disassembled, and their components re-used.

4. Makerspace areas, toolkits and machinery

A makerspace may contain areas in which different types of activities are carried out using specific tools, machinery and materials. These activities may include:

- Basic design and creation
- Sewing and textiles
- Joinery
- Metalworking
- Electronics, coding and robotics
- Digital fabrication
  - 3D printing using various materials such as plastics, ceramics, chocolate
  - Vacuum plastic forming
  - Plastic bending
  - Computer Numerical Control (CNC) cutting of various materials
  - Laser Cutting of various materials
- Analogue photography and film making
- Information technology

The following sections describe activities carried out, and provide examples of the tools and machinery used, in different areas often found in makerspaces. The toolkit examples are not intended to be exhaustive, nor are they intended as lists of must have items. They are intended to give an indication of the types of tools that may be used in various makerspace areas and they have been informed by the equipment used in the case study schools.

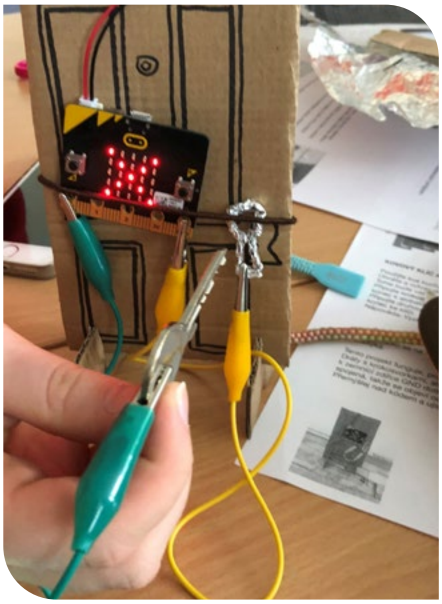
27 Olson, R., 2013. "A boon or bane?" The Environmental Forum, 30(6), pp.34–38 quoted in Smith, Adrian and Light, Ann (2017) "Cultivating sustainable developments with makerspaces", available from Sussex Research Online: http://sro.sussex.ac.uk/id/eprint/68515/

Some schools have had some unusual ideas for other makerspace activities or areas, or have included in their makerspaces activities that in other schools may be found in other specialist classrooms:

- The Czech case study school has plans to create an aquaponics centre, which will be managed mainly online so students will have a chance to further develop computer skills as well as learning new practical biology skills. The school say they would also like to buy Robotic Arms for use in the centre so that students could explore how industrial robots work.
- Base 1 makerspace in Luxembourg has a music technology section where students and other users of the space can learn to use technologies such as keyboard controllers[28].
- Fernando Casimiro school in Portugal has a pottery area in their makerspace, including a potter's wheel and a clay oven.

4.1 Basic design and creation

The basic tools needed in a makerspace are related to everyday creativity, including design, measuring, cutting, pasting and screwing. These actions are carried out by students of all ages, and this can include kindergarten classes. Of course, attention must also be paid to the tools, for example blunt ended scissors for young children, and to the accessories needed to ensure a safe operating environment, including gloves, dust masks, safety glasses, etc.



As students and teachers gradually become familiar with the activities of the makerspace, more complex activities can be introduced. These may involve the use of different types of materials and the machines required to process these appropriately. Involving students in projects that require the understanding, and use of, multiple types of manufacture, such as electronics and mechanics, creates a learning environment that is closer to real life than the separate academic study of single subjects.

BASIC DESIGN AND CREATION TOOLKIT			
	Scissors, Hacksaws and Snap-off Knives	Hand lettering kits	Manual and Cordless Drills and Screwdrivers
	Tape measures	Glue and paints	Brushes
	Spanners and Allen keys	Hammers	Nails, Screws, Fasteners
	Cardboard construction kits (e.g. Makedo)	Plastic construction kits (e.g. Lego, Fischertecnick)	Simple electronic compo-nents and wire
	Simple circuit drawing kits (e.g. Circuit Scribe basic kit)		
	Desktop digital cutter plotter for paper, vinyl, fabric, etc. (e.g. Silhouette Cameo)		

4.2 Sewing and Textiles

In this area students can work with fabrics, vinyl, leather, yarns and other flexible materials. They can sew, repair and modify clothes, create home decorations and accessories (aprons, gloves, tool belts, etc.) as well as component parts of jewellery.

28 A keyboard controller is used for sending MIDI (Musical Instrument Digital Interface technical standard) signals or commands via a USB or another cable to musical devices or computers.

SEWING & TEXTILES TOOLKIT TOOLKIT	Sewing machine	Fabrics	Elastic
	Embroidery machine		
	Heat press to print on fabric	Leather	Tailors chalk
	Punches for engraving	Synthetic materials	Fabric glue
	Iron and ironing board	such as vinyl, nylon	Pins
	Sewing scissors	Buttons, poppers, zips	Threads
	Needles and threaders	Beads and trimmings	Seam rippers

4.3 Joinery

Wood is an economical, durable, attractive, renewable (although some care needs to be exercised to ensure sustainable wood is used) and readily available material in many standard sizes. Many tools needed to process it are part of the basic kit of a makerspace. More specialist or larger tools and machines may be needed for precision work or when building using large pieces of wood. Wood is a very useful and practical material for use by pupils of all ages as it is versatile and relatively easy to work.

JOINERY TOOLKIT	Manual and Jig Saws	Circular Saw	Nails
	Planes	Sander	Screws
	Screwdrivers	Sandpapers	Hammers
	Chisels and Files for wood	Vice and Clamps	Drill, Drilling machine, drill bits
	Wood turning lathe	Wood glue and Glue Gun	

4.4 Metalwork

In the area dedicated to working with metal, students can potentially build anything; including very small or very large objects, prototype solutions or very advanced products. Simple devices consisting of levers or gears can be considered the basics of mechanical construction, accessible to young children. Older students may create stable platforms for robots or metal cases for electronic devices. It is possible to go as far as the construction of spare parts for cars, bicycles and other vehicles.

METALWORK TOOLKIT	Welding tools	Hammers	Pliers
	Column drill	Screws	Metal polishing brushes
	Drill bits	Bolts	Clamps
	Cutters	Wire – various metals	Iron files
	Anvil	Spanners and Wrenches	Metalworking lathe

4.5 Electronics, coding and robotics

Activities in this area of a makerspace include the construction of electrical circuits as well as programming microcontrollers, microcomputers or robots; including using sensors so that constructed objects can react to their environment. Here students will:

- Develop their understanding of the principles and practicalities of electronics and microelectronics.
- Learn to read and design integrated circuits and understand wiring diagrams.
- Develop and put into to practise their coding skills.
- Gain practical experience of combining hardware and software into objects that interact with the real world.

Each activity needs to be tailored to the age of the students. Younger students will approach electronics through specially designed kits such as Little Bits or Sam Lab. Older students can use wires and components and soldering irons.

Activities can also involve microcontrollers that enable the creation of robots of different types and complexity. When students are constructing robots from scratch they will need to develop knowledge and skills that combine electronics with woodwork, metalworking or the use of 3D printers. Drones, aircraft or hovercraft can also be created using kits such as Airblock[29].

ELECTRONICS, CODING & ROBOTICS TOOLKIT	Batteries	Electric cables	Sensors : light, movement, humidity, etc.
	Multimeter & tester	Capacitors	Wireless electronic blocks (e.g. Sam Lab)
	Accelerometers	Switches	Electronic building blocks (e.g. Little Bits)
	Motors – servo, continuous, stepper	LEDs, Bells and Buzzers	Programmable robots (e.g. Thymio,, Bee-bots, Ozobots, Dash & Dot, mBot, Cubetto, Edison, Sphero)
	Oscilloscope	Fans	Drone construction kits (e.g. Airblock)
	Resistors and Diodes	Soldering iron and Solder	Micro controllers or micro computers (e.g. Arduino, Micro:bits, Calliope Mini)
	Transistors		
	Breadboards	Potentiometers	Alligator clip connectors, Jumper wires
	Electronic invention kits (e.g. Makey Makey)		
	Physical plus digital educational gaming kits (e.g. Osmo)		

29 Airblock is made of magnetic, modular parts that are easy to assemble and disassemble without the need for tools.

4.6 Digital fabrication

Digital fabrication combines design and manufacturing into processes in which data directly drives manufacturing equipment to create parts and products.

The design work is carried out using computer-aided design (CAD) and computer-aided manufacturing (CAM) software. The output data from use of this software is then used to instruct machines like 3D printers, Computer Numerical Control (CNC) milling machines or laser cutters.

4.6.1 Plastic fabrication

In the industrial context there are many ways of manufacturing plastic objects some of which involve very complex and expensive processes and machinery.

In school makerspaces plastic forming involves 3D printing and heating and shaping plastic sheets.

A plastic sheet can be placed in a **vacuum plastic forming machine**, heated to a forming temperature, stretched onto a single-surface mould, and forced against the mould by a vacuum, resulting in the plastic being imprinted with the shape of the mould. Rigid plastic sheets can also be neatly bent using a **plastic bending machine**.

4.6.2 3D printing

3D printing builds a three-dimensional object, from a computer-aided design (CAD) model, by adding layers of material; it is therefore known as an additive manufacturing process. 3D printers in makerspaces are normally filament printers; which use a continuous filament of material, fed through a moving, heated printer extruder head to create the layers deposited onto the object being built.

INDIRE's Maker@Scuola project[30] in 2017 analysed and demonstrated the effectiveness of the use of 3D printers in kindergarten and primary schools to support innovative teaching centred on a positive approach to learning through experimentation and problem solving.

Young students can be supported to solve simple problems that involve the construction of pieces using the 3D printer. Older students can use the 3D printer for rapid prototyping and the creation of customised parts, which can be used with wooden and metal parts in mechanical, electromechanical and mechatronic[31] projects. 3D printing can also be used to repair defective objects or to create custom-made spare parts. This aspect of 3D printing is particularly compatible with the philosophy of the makerspace which includes promoting reuse and recycling of materials.

There are many software applications that can be used for 3D drawings and to export models for printing. Popular free software includes SugarCad (developed by INDIRE) and TinkerCAD, for kindergarten students; and SketchUp, Blender and Autodesk 123D which have more features for older students. Commercial software includes Rhino, Autodesk Inventor and SolidWorks. Commercial software can be very expensive, although many companies offer educational discounts.

3D printers typically use thermoplastic filament to create plastic objects. However, specialised 3D printers can be used to create objects in other materials. For instance, Second Comprehensive Institute Montessori-Bilotta in Italy uses one machine to "print" with ceramic material and another which is used to "print" in chocolate.

30 Guasti, L., & Rosa, A. (2017). Maker@ Scuola. Stampanti 3D nella scuola dell'infanzia. Firenze, Assopiù Editore, 91-106. http://www.indire.it/wp-content/uploads/2017/09/Libro-Maker-a-Scuola_2017.pdf

31 Mechatronics is an interdisciplinary area of engineering that combines mechanical and electrical engineering and computer science.

4.6.3 Desktop inkjet printer/cutters

Desktop combined printing and cutting machines can be used for printing and cutting into the correct shape designs that students have created on a computer. These machines are often used to print and cut vinyl material to create t-shirt graphics, posters, stickers, labels and decals.

4.6.4 Laser cutting

Laser cutting machines enable rapid cutting and allow students to precisely cut very complex shapes in flat materials such as paper, wood, acrylic panels, cardboard and felt. It is then possible to assemble these flat shapes to create 3D structures, possibly combining them with other materials. Drawings and engravings can also be made on the surfaces of materials. The use of laser cutters can be combined with carpentry or mechanics.

Laser cutters are professional machines that require the presence of expert technical personnel to support students and teachers. The main safety risk when using a laser cutter is fire within the machine itself. A laser cutter machine should never be left to work unattended, as even a small fire can cause costly damage to the equipment. There should be a CO_2 extinguisher easily accessible near the cutter. This type of extinguisher can be used to extinguish fires without causing damage to machinery. A secondary risk is the emission of fumes. As the laser vaporises the material gases are released. If the cutter does not have adequate external ventilation, it is necessary to install a very efficient filter.

4.6.5 CNC cutting

Computer Numerical Control (CNC) milling machines allow precise processing of a variety of materials, including metals, wood and plastics, thanks to the digital control on the rotary cutters that can cut, carve and shape a wide variety of materials in three dimensions. These machines differ from laser cutting machines due to this ability to cut in three dimensions. They can also cut a wider range of materials and, above all, thicker materials. CNC cutters are professional machines that require the presence of expert technical personnel to support students and teachers.

4.7 Film making and analogue photography

In a learning lab, or other specialist area within a school, students are able to carry out many creative learning activities involving still and video photography whilst exploiting the latest digital tools.

In some schools, students working in a makerspace may create stop motion animated films with figures that they have created using plasticine or a 3D printer. In one of the case study schools students used Playmobile figures. Green screens are also sometimes used to place students within digital films. Digital film making can be considered to be a boundary activity which may take place in a makerspace or in a learning lab or both. The cameras used for this activity can be included in the Information Technology toolkit.

In a darkroom in a makerspace, students can explore some of the basic rules of physics, optics and chemistry and learn the principles that underlie analogue photography. With age-appropriate supervision students of all ages can use a darkroom.

DARKROOM TOOLKIT	Dedicated red light room	Film processing equipment
	Wash basins	Including film containers, holders, etc.
	Chemical reagent cabinet	Magnifier for printing
	Printing trays	Consumable materials
	Various instruments e.g. tweezers	Including printing paper and chemical reagents

4.8 Information technology

In this area of a makerspace students use desktop computers, laptops, netbooks, tablets and smartphones and the Internet, collaboratively or individually, to access information necessary for many activities and to carry out design work. For 3D modelling, and other precise design tasks, workstations with larger monitors are helpful. A 3D scanner can be used to capture a physical object's exact size and shape as a digital 3-dimensional representation which students can then manipulate via a computer.

Printers in this area can be used to produce models, drawings, decorations, manuals and explanatory materials. This is a very important aspect in relation to the quality and sustainability of a manufacturing laboratory.

The IT area is closely linked to all other areas of the makerspace and the computers can be used to produce and share information about, and outputs from, projects carried out. Cameras and blogging applications can be used to document and disseminate students' work.

Cameras can also be used together with computers and a green screen to place students virtually inside the products they create or other locations. A green screen and video camera may be available in the makerspace or in an adjacent learning lab space.

5. Sustainability

Once a makerspace has been created and is operational, a school is faced with the challenge of ensuring that they can afford to keep it running, and providing benefits for the students and the school, in the long term.

Ideally schools will start planning for sustainability even before a makerspace is set up, especially as the initial set-up costs often come, totally or partially, from short-term sources such as project funding, industry donations or grants from charitable foundations.

The case study schools described four different approaches to sustainability:

- **School funding and fund raising**

Both of the Irish case study schools envisage future maintenance and running of their makerspaces being funded, totally or partially, by fund raising activities with the balance of the money required coming from the school's budget.

In Portugal, Fernando Casimiro Pereira da Silva school will continue to seek funding from the local community and from the municipality as well as allocating some school funding to their makerspace. Freixo school will uses some of their own budget and continue to bid for funded projects that will allow for acquisition of equipment and financing of activities.

The creation of the makerspace at Baar school in Switzerland was initially funded by a charitable foundation but now, and in future, funding will come from the school's library and informatics budgets. Also, due to the success of the makerspace, the school has allocated regular additional funding of 1000 Swiss francs (approximately 900 euros) a year to renew equipment and develop the makerspace services.

The makerspace at Tofaş Science High School in Turkey was built by the Tofaş vehicle manufacturing company. The company is continuing to provide materials requested by the school. It is anticipated that this industry partner will go on supporting the makerspace initiative in future, including funding specific projects proposed by the students. When insufficient funding is available via this route, the school will allocate money from its own budget.

- **School and local authority, national funding or EU funding**

At Silberberg Primary school in Switzerland the makerspace has been funded by a charitable foundation as part of a research project. This project will soon end, and then the makerspace equipment and running costs will be funded by the local authorities within the regular school budget. Also, the local authorities have agreed to pay for the part of the teacher/makerspace manager's time (20%) that is dedicated to the makerspace for one more school year.

Afterwards, this the school is not sure how they will fund continuation of the makerspace. There are options to develop it further in connection with the new curriculum, which could help with funding. Also, as the teachers are being trained for the new curriculum, there will be more staff with the skills needed to use the makerspace, in particular related to the work with programmable devices.

The Karaköprü makerspace in Turkey, which is shared by two local schools, expects to receive continued financial support from the Municipality. Although they believe that other public bodies and students' families would support the space if necessary. The makerspace manager plans to seek funding to increase the maker skills of teachers and to double the number of teacher training events. The training will also be available to teachers from nearby schools.

Dr Edvard Benes, Praha - Čakovice, school in the Czech Republic say they will continue to seek opportunities to take part in national or international funded projects and will also apply for any grants that become available.

- **Creating a self-supporting community**

The Austrian case study schools both plan to fund their makerspaces in future from membership fees paid by members of the maker community they plan to develop. Continued contributions from the industry sponsors are also anticipated.

- **Creating a public-private partnership**

The Italian case study schools both plan to use a type of public-private partnership model to maintain and develop their makerspaces in future.

Some teachers and parents from Montessori-Bilotta school have created an association that will develop and maintain the makerspace, organise the timetable and propose technical training. The association will use the makerspace when the school is closed to run courses for external customers who will pay for this service. The schools sees this as a win-win situation in which the school has a well organised and up-to-date makerspace, and the association also has access to the space with the added benefit of being associated with the school's reputation as an educational institution.

IC Lucio Fontana operated a similar model from the beginning with three partners:

- The local council renovated a school lab to create the makerspace.
- An external makers association provided equipment, managers, maintenance and training courses for teachers.
- The school provided utilities and made the space available to the makers association in extracurricular time to run fee paying courses.

Unfortunately, the makers association "*broke up for members' private reasons*" so currently the school is advertising for a management service which will have the same responsibilities the makers association had.

Glossary

Coding, invention and creation kits

Google Cardboard: a virtual reality platform using fold-out cardboard viewers into which a smartphone is inserted, a low-cost system to encourage interest in and development of VR applications. *https://arvr.google.com/cardboard/*

Kitronic inventors kit: a kit to help students start programming and hardware interaction with the BBC micro:bit . contains LEDs, motors, LDRs and capacitors. *https://www.kitronik.co.uk/blog/kitronik-inventors-kit-resources/*

Little Bits: a system of modular electronic building blocks, which snap together with small magnets for prototyping and learning. *https://littlebits.com/pages/shop*

Makey Makey: an electronic invention kit. *www.makeymakey.com*

Osmo: a creation kit which combines digital and real world objects and materials. *www.playosmo.com/en/*

Sam Labs: kits of wireless electronic blocks with different functions e.g. lights, sensors, buzzers that can be connected to achieve simple reactions or create complex objects by incorporating several blocks and other material e.g. cardboard. *https://uk.samlabs.com/*

Scootie Go!: a game to teach programming that combines the use of cardboard tiles with an app. *https://scottiego.com/en/*

WeDo 2.0: a primary school science and computing projects kit including Lego pieces plus Smarthub, motor, motion sensor and tilt sensor, and an easy-to-use programming environment. *https://education.lego.com/en-gb/product/wedo-2*

Construction and assembly kits

Fischertecnick: sets of nylon bricks plus electrical and electronic components used to construct simple machines and to learn about motorisation, automation and robotics. *https://www.fischertechnik.de/en*

Lego: sets of interlocking plastic bricks, wheels and other shapes, that can be used to construct many different shapes and objects, plus some figurines. *www.Lego.com*

Lego Technic: Lego sets including gears, axles, pins, beams and plates with holes for axles, pneumatic pieces and electric motors, used to build working vehicles and robots. *www.lego.com/technic*

Makeblock Airblock: sets of magnetic, modular parts, that are easy to assemble and disassemble without the need for tools, used for making drones, aeroplanes and hovercraft. *https://www.makeblock.com/steam-kits/airblock*

Makedo: a simple to use system of tools for building imaginative and useful creations from recycled cardboard. *https://int.make.do/*

Electronic tools and components

Accelerometer: detects and responds to changes in acceleration.

Alligator clip: used between an electronic circuit and a measurement device to provide a temporary electrical connection.

Breadboard: a construction base for prototyping electronics and testing circuit designs.

Capacitor: a device that stores electrical energy.

Diode: a semiconductor with two terminals, typically allowing the flow of current in one direction only.

Jumper wire: an electrical wire, or group of them, with a connector or pin at each end, used to interconnect the components of a breadboard or other test circuit without soldering.

LED: Light emitting diode, a two-lead semiconductor light source.

LDR: Light Dependent Resistor, used to sense the absence and presence of the light.

Multimeter: a device that measures and displays capacitance, current, frequency, resistance, voltage, etc.

Oscilloscope: a device that displays and measures waveforms using amplitude or strength of the signal on the y-axis and time on the x-axis.

Potentiometer: a variable resistor that is adjusted either manually or digitally.

Resistor: a passive component that resists or regulates the flow of current and is used to limit the current to a component or circuit.

Transistor: a semiconductor with three connections that can act as an amplifier or a switch.

Microcomputers and microprocessors

Arduino board: a mini-computer on a single small circuit board. The Arduino company also produces microcontroller kits for building digital devices. *https://www.arduino.cc/en/Guide/Introduction*

BBC micro:bit: a mini-computer on a circuit board half the size of a credit card. Several different code editors and many different programming languages can be used to programme the micro:bit. *https://microbit.org/*

Calliope Mini: a mini-computer on a small star-shaped circuit board that can be programmed using block-based or text programming languages. *https://calliope.cc/en*

Kniwwelino: a kit consisting of an Arduino compatible microcontroller board with built-in WiFi and a visual online programming environment. *https://www.kniwwelino.lu/en/*

Oxocard: a mini-computer on a small single circuit board with WiFi that can be programmed using the Google Blockly programming environment. *https://oxocard.ch/*

Raspberry Pi: a range of small single-board mini computers developed by the Raspberry Pi Foundation to promote teaching of basic computer science in schools and in developing countries. A number of Raspberry Pi accessories are available including keyboard, mouse, display and cameras. *https://www.raspberrypi.org/*

Robots and robotics kits

Bee-bots: small colourful robots designed for teaching young children sequencing, estimation and problem-solving. Directional keys are used to enter up to 40 commands that send the robot forward, back, left, and right on a journey. *https://www.terrapinlogo.com/products/robots/bee-bot/beebot.html*

Blue Bots: small programmable floor robots for young children that can be wirelessly controlled using a tablet or PC. *https://www.tts-group.co.uk/blue-bot-bluetooth-programmable-floor-robot/1015269.html*

Cubetto: a small wooden robot designed to teach very young children the basics on coding using boards and blocks. *https://www.primotoys.com/*

Dash and dot: Dash is a small colourful programmable robot with multiple sensors that interacts with, and responds to, its surroundings. Dot is a creativity kit centred around a programmable ball. *www.makewonder.com/robots/*

Edison: a small, cost effective programmable robot. *https://meetedison.com/*

Lego Mindstorms EV3: a hardware and software set for creating programmable robots based on Lego building blocks plus a microcontroller, modular sensors and motors, and Lego Technic parts. *https://www.lego.com/en-gb/product/lego-mindstorms-ev3-31313*

mBot: a STEAM education robot for beginners, with just a screwdriver, the step by step instructions, and a study schedule, children can build a robot from scratch. *https://www.makeblock.com/steam-kits/mbot*

mBot Ranger: programmable robot construction kits have about 100 mechanical parts and electronic modules. There are 3 pre-set forms: a tank, a three-wheel racing car, and a self-balancing "Nervous Bird". *https://www.makeblock.com/steam-kits/mbot-ranger*

Ozobots: small round robots that young children can control by drawing colour coded tracks and older students can programme using a visual programming language based on Google Blockly. *https://ozobot.com/*

Sphero: combines a range of small programmable robots with apps and STEAM activities and programmes. *https://www.sphero.com/education/*

Thymio robot: an educational robot with sensors and actuators enabling interactivity based on light and touch that can be coded with graphical and text programming languages. *https://www.thymio.org/*

Vex robotics: supplies kits that allow students of various ages to construct and programme robots, supplies educational resources for teachers and organises competitions for teams of robot builders. *https://www.vexrobotics.com/*

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Makerspaces in schools

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