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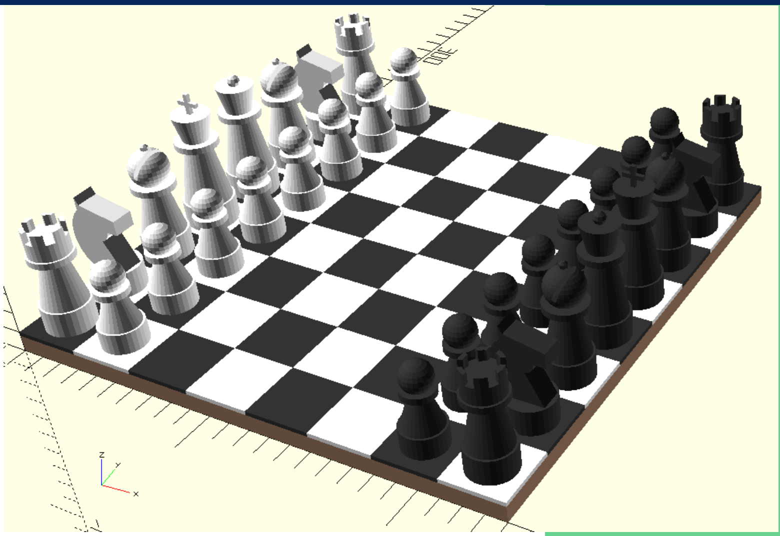
Classroom Guide to Teaching about and through 3D

Teaching and learning methods relevant to creative 3D design and 3D printing



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Project "MAKER SCHOOLS: Enhancing Student Creativity and STEM Engagement by Integrating 3D Design and Programming into Secondary School Learning" (Agreement no. 2020-1-BG01-KA201-079274)

MAKER SCHOOLS
3D Design for Education

Contents

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EdTech in schools

The young generation has grown up with digital devices and is comfortable with a variety of innovative and continuously changing technologies. Such early exposure to new technologies influences many aspects of students' lives, including the way they learn. Students' demand for technological innovations in schools, coupled with technological advancement and lower equipment costs, are even bringing 3D printers to an increasing number of secondary schools.

In the face of this change, we are naturally asking ourselves what this would mean for secondary education. 3D design and printing is an essential part of STEAM (Science, Technology, Engineering, Arts, and Mathematics). The general consensus is that 3D technology provides opportunities for creativity and can overcome student perceptions that STEM is uninteresting, unappealing and difficult. 3D printers and 3D modelling software can create a more open-ended and student-centered learning experience. However, they invariably come with caveats and create new challenges. At the very least, they require less conventional teaching and learning approaches.

Teachers tend to have a complicated relationship with technology in schools. Some embrace the abundance of easily accessible online learning resources and tend to be early adopters of technology, new tools and platforms, seeing them as an opportunity to engage students in new ways. These teachers are usually comfortable experimenting with new tools and are excited about the potential of technology to enhance student learning.

Other teachers, however, are more hesitant to adopt new technologies, either because they are not confident in their own ability to use them effectively or because they are altogether sceptical about the benefits of technology in the classroom. They may regard technology as a distraction, as a substitute for creativity, critical thinking and in-depth analysis, or as an unnecessary investment of both time and money.

Regardless of their attitudes towards technology, it is important for teachers to stay informed about the latest developments in EdTech and to be willing to explore new tools and platforms when appropriate. By doing so, they can ensure that their students are prepared for the demands of a rapidly changing digital landscape and are equipped with the skills they need to succeed in the 21st century. Despite the unavoidable controversies surrounding EdTech, we believe teachers are always motivated to make teaching more effective, to enhance their students' learning experience, and to address important real-world skills. If 3D technology can help realize these goals without drastically disrupting the learning process, most teachers would embrace it. Therefore, below we set out to review both the benefits of using 3D technology in secondary schools and the potential challenges it brings. On this basis we will discuss and propose alternative teaching and learning methods and techniques that can guarantee effective student exposure to 3D technology.

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Benefits of bringing 3D technology to secondary school classrooms

Experts agree that there are many benefits of using 3D technology in secondary education. Some of the most notable ones are:

- **Improved learning experience**: 3D technology can enhance learning environments by providing a more immersive and interactive experience that allows students to better understand complex concepts and subjects.
- **Visualization of complex concepts**: 3D models can help students visualize complex concepts in science, mathematics, and other subjects. For example, a 3D model of a molecule can help students understand its structure and how it interacts with other molecules.
- **Increased engagement**: 3D models are interactive. They can be manipulated and tested. When used for prototyping or creation, 3D printing allows students to see their ideas become real objects. Thus, 3D technology can make learning more engaging and interesting. Moreover, since 3D simulation software is similar to computer/video games, students are more likely to remain interested and enjoy the learning process. This can help them stay focused on the learning material, which can lead to better retention of information.
- **Smooth transition from learning to practice**: Learning through 3D is less abstract and much more applicable to real-world environments. It allows students to understand how things work and to test printed designs. It can thus bridge theory and practice and motivate students to think about the potential applications of what they have learned in theory. It is positive that, through 3D learning, practical processes can be simulated without expensive equipment or access to physical objects that could potentially be damaged or that are not accessible at all.
- **Democratizing effect on the education system**: If equipped with 3D printers, schools no longer need sophisticated laboratories where students could handle objects and specimen. With 3D models that can be easily found online and printed, even schools with fewer resources can allow meaningful learning and practical engagement of their students.
- **Compatibility with online learning environments**: 3D modelling can be easily incorporated into online and distance education.
- **Interdisciplinarity**: 3D technology promotes interdisciplinary learning and helps to remove the barriers between previously isolated disciplines (e.g. if students work on a 3D design of a molecule, they engage both with Chemistry and Geometry).
- **Career orientation**: 3D technology can motivate students with different profiles and aptitudes to pursue a career in STEAM, and help them gain the confidence that they can succeed in it.

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Skills that students can develop or improve by engaging with 3D technology

3D design and printing (especially when combined with programming) can help students develop or improve a range of knowledge, skills and competencies that are valuable in both academic and professional settings:

- **Computer literacy and a variety of technical skills** in using 3D design software, operating 3D printers, and writing code.
- **Understanding of geometry and algebra**.
- **Spatial thinking and spatial intelligence**: 3D technology requires students to think spatially, as they create objects in three dimensions. This can help them develop spatial reasoning skills, which are important in fields like engineering and architecture. These skills can boost students' overall performance in STEM disciplines.
- **Understanding and learning of abstract concepts**.
- **Collaboration**: Working on 3D design and printing projects often involves collaboration, as students work together in teams. This can develop teamwork and communication skills.
- **Creativity and problem-solving**: Designing and printing 3D objects often involves problem-solving and critical thinking, as students need to identify and overcome design challenges. Programming for 3D can also be a very creative process, as students use code to create digital solutions for 3D models.
- **Understanding and skills in design processes**: Students can develop their ability to create functional designs, as well as to identify poorly designed and non-functional products or ethically inappropriate designs. They can boost their understanding of the principles of design and be sensitized to the requirements of user-centered design, and ergonomics.
- **Attention to detail and precision**: Designing and printing 3D objects requires a high level of attention to detail, as even small errors can have a significant impact on the final product.
- **Project management:** Completing 3D design and printing projects requires students to manage their time and resources effectively. This can develop project management skills that are valuable in a wide range of fields.
- **Preparedness for future careers:** Many industries, including Engineering, Architecture, and Manufacturing, rely heavily on 3D technology. By learning how to work with 3D technology in secondary education, students can prepare for future careers in these fields. Moreover, knowledge of 3D design can enhance young people's capacity to effectively use other complex emerging technologies such as Virtual Reality, Augmented Reality, and digital fabrication. The process of using 3D in the classroom is similar or identical to that used by engineers and designers, and so can have strong impact on students' employability.
- **Entrepreneurship skills** can be developed as a result of better understanding of design requirements. 3D technology can help also in the idea generation process and sensitize future entrepreneurs to good practices in product design.

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Challenges with using 3D technology in the classroom

Both teachers and students can expect to meet some challenges when starting with 3D technology in the classroom:

- The process of 3D modelling and printing has a **steep learning curve**. 3D technology projects typically require completing some form of training before actual work can start, or need to be long-term engagements during which students or teachers would effectively learn while working on practical projects. In addition, even after training, project work would likely require substantial investment of time and effort on the part of both teachers and students. Optimizing design so that the product is functional and printable, pre- and post-processing, error control, and hardware and maintenance issues are some of the most notable challenges that users of the technology grapple with.

- 3D modelling and printing can be **disheartening** and unnerving, or it can simply turn out to be too **time-consuming** for students and teachers who are already struggling with busy schedules. 3D design and printing is still a relatively slow process, even for small objects. For large objects, the printing process alone might take a few hours, depending on the fill, the printer model and the print speed. It is useful to keep in mind that 3D modelling and printing typically involve trial and error, and often it is necessary to make corrections in the model and repeat the printing process a few times before the result is satisfactory. To make matters worse, consumer-based 3D printers are in relatively early stages of development, so they themselves cause glitches that can result in failed prints.

- 3D technology **disrupts the familiar traditional teaching and learning processes**. For teachers and learners who feel more comfortable with traditional teaching methods, such as lectures, group discussions, textbooks and worksheets, homeworks, and tests, 3D technology-based learning would probably not be a comfortable alternative. Some teachers can feel overwhelmed by the new technology and they may feel that it adds to their workload and makes their job more difficult.

- 3D modelling and printing **challenges the traditional power dynamics in the classroom**. Due to students' familiarity and comfort with complex technologies, the teacher would not necessarily be the expert and the student would not necessarily be the novice. In some cases, students may be more familiar with the technology or they may learn to use the software faster than their teachers. Before venturing into 3D applications in the classroom, teachers should be prepared for a more equal relationship with their students and should not be concerned that their authority may be undermined if the students turn out to be more knowledgeable or skilled than they are.

- Teachers and students often find the **3D modelling software difficult to use**, for different reasons. Some may find it too simple for their complex designs (e.g. in Arts or History classes), others may have trouble figuring out how to make their designs printable, and still others may simply be overwhelmed by the software interface. It is often necessary to have a teacher or a technician work directly with students to help them modify their designs to ensure that they are structurally sound. As an alternative, students who are familiar with 3D modelling can be asked to teach and support their classmates during the 3D design process. If students appear openly frustrated, it may be necessary to provide reassurance and support to help them continue using the modelling software. Despite the dedication of the instructor or the additional facilitators, students may simply need additional training or time to play around with the software and read the tutorials before starting the project. For students without a strong STEM aptitude or in cases where a lot of creativity is encouraged, teachers may consider creating a low-tech makerspace first, where students can construct physical objects to represent their designs before using the 3D modelling software.

- It may be **challenging to continually engage students in a long-form project**. 3D technology-based projects are not very suitable for short exercises. On the positive side, longer projects give students more responsibility and agency, and teach them about time management, communication, collaboration, and self-motivated research and exploration practices.

- Teachers and students **may initially find it difficult to imagine effective ways to use 3D printed objects in the learning process**. Awareness raising, sharing of good practices and ideas, or dedicated brainstorming exercises may be needed to cultivate the idea of using 3D technology in schools and to motivate further exploration and efforts in that direction. This often requires additional time and the dedication of a change-maker core of educational experts, teachers or school practitioners.

- 3D modelling software allows for superior interactivity of the design, but can also **limit creative thinking if overused**.

When to use 3D printing in learning

As a rule, if a teacher feels it would be beneficial to use photos, schemes, diagrams, audio or video in the teaching process, then students would potentially benefit also from using 3D models. The 3D model would enhance the ability of students to perceive and comprehend concepts and understand the subject matter. If the school has the necessary technology, experimenting with 3D would most likely improve the learning process and be appreciated by students.

Before proceeding with 3D technology innovations, schools need to ensure that basic enabling conditions are met. Like most technology integration efforts in schools, teachers need to have support or prior training for using 3D printers before they venture into 3D-enabled learning. Such support and training can address many of the challenges we mentioned. To motivate teachers, incentives need to be put in place to reward their innovative ideas and approaches and their additional efforts for professional development. For 3D-enabled learning to be effective, it may be advisable for teachers in specific disciplines to partner with technical experts or other teachers that are more confident in using 3D technology. Finding ways to enable and facilitate such collaboration within the school itself, or through external partnerships and communities of practice, is essential for the success of all EdTech innovations, including 3D technology integration.

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Setting up the classroom for 3D technology integration

- 3D design software

Tinkercad and Fusion 360 are free for educational purposes in schools. Tinkercad is a good starting point but more sophisticated software solutions such as Fusion 360 would be beneficial once users have mastered Tinkercad, or when precise and advanced projects are planned. You can see additional software options in the MAKER SCHOOLS modules, especially in the Module "3D Printing Technologies, Materials and Software Applications".

- Equipment

The desktop or laptop device specifications needed for a 3D technology-based project would depend on what software for 3D modelling will be used. Any computer or laptop will be good for Tinkercad, and the only requirements are internet connection and the latest version of a popular browser. However, for other software options there are additional hardware requirements that can be found on the software download pages (for Fusion 360, see the specs here: https://knowledge.autodesk.com/support/fusion-360/learn-explore/caas/sfdcarticles/sfdcarticles/System-requirements-for-Autodesk-Fusion-360.html).
Teachers either need to find the proper computer devices for the chosen software, or adjust the tasks so that they can be carried out with software that will run smoothly on the available devices. 3D design and printing can become very frustrating and slow if the tasks are performed on devices without the necessary computing power or without good internet connection.

Regardless of the chosen software and device, a traditional computer mouse is strongly advised when working on 3D models. Using the touchpad will slow down the process and be less comfortable.

- Other materials

A temporary low-tech makerspace is not required but can be useful in some more complex student projects. Such a makerspace can feature various materials, including clay, sticks and toothpicks, glue, pipes, string, as well as paper for brainstorming and drawing design ideas before students start working on computers.

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Educational approaches suitable for integrating 3D technology in education

- Student-centeredness

3D modelling and printing projects require student-centered teaching approaches, in which students are given substantial degree of responsibility for what is being learned. Teachers on the other hand become partners in the learning process, guiding the students' work, as opposed to delivering knowledge.

- Learning-by-doing

In order to introduce 3D technology projects into learning, both students and teachers need to be comfortable with adopting a learning-by-doing approach. Students will be expected to explore the academic material in various disciplines through creation rather than through consumption of content. Classroom activities would become less teacher-centered and less focused on didactic presentation, and will instead be more interactive and learner-centered. Instruction-wise, there will be less emphasis on fact memorization and more focus on problem solving and analysis. Computers and digital tools will not just be used for work and practice, but also for communication. Assessment will also need to change, as progress and success will be evaluated with regard to the quality achieved and not with regard to the quantity of output.

- Active learning, experiential learning and design-based learning

3D modelling and printing projects are a great fit for approaches that allow for active, experiential, student-driven learning, such as makerspaces and design thinking. One of the key advantages of 3D technology is that it can enable experiential teaching and learning in many disciplines where it would otherwise be challenging or impossible. Student exploration of relevant physical models can promote engagement and deepen knowledge of course material by adding tactile modes of learning. The benefits can be even greater if the activity relies on a collaborative learning approach. Teachers can promote active learning both by using readily available 3D models to print ahead of the activity, or by allowing students to design and print a relevant 3D model.

Makerspaces are collaborative learning environments where people create, invent, and learn using a variety of tools and technologies. They thrive on, and in turn promote, creativity, collaboration, and innovation. These spaces can include equipment such as 3D printers, laser cutters, CNC machines, and digital prototyping tools, as well as traditional tools like drawing boards, hand saws, drills, and hammers. These are the perfect places to organize student 3D projects. Maker technologies can be used for a wide range of projects, from creating art and jewellery to building robots and drones. The commonality between these projects is that students will learn while producing artefacts that are technologically-enhanced. Knowledge is thus not delivered to the learner but constructed by the learner.

Design-based learning is a sub-type of problem-based learning. It compels learners to carry out investigations, integrate theory and practice, and apply their knowledge and skills to develop a viable solution to a problem. It involves an open-ended process of innovation, trial and error, and iteration. 3D design projects can be easily adapted to follow the design thinking approach, thus also preparing students for design-based careers or careers in Industry 4.0.

Both makerspaces and design-based learning activities nurture students' creative thinking, inquiry learning, and problem-solving skills. They require and promote learner engagement and learner autonomy. They compel students to provide explanations, make predictions, and support their ideas, which builds skills that go beyond the low-level skills fostered in compulsory curricula to multileveled skills and ability to use interconnected bodies of knowledge. They are suitable for all students, including low achievers. They are auspicious for peer collaboration and teamwork, and

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can thus also close the achievement gap between students. In addition, there are some notably positive psychological effects associated with these approaches. The hands-on experience of creating something results in a sense of pride and personal fulfilment, and promotes a sense of ownership of the learning process and of the student's own creativity.

- Inclusive teaching

Learning activities exploiting 3D design and printing are suitable for instructors who are focused on inclusive teaching. Whether involving programming or not, such activities typically necessitate collaboration and require that all students are involved in the activity in assigned roles within a team. This makes it possible to engage the whole group of learners effectively. Learners who face some disadvantages can thus get involved in areas where they feel more confident and knowledgeable. The collaborative environment promotes a general respect for different opinions and skills within the group of learners, which is also beneficial for those with disadvantages. In addition, 3D technology projects involve a number of different modes of instruction, which makes learning more accessible and suitable for learners with disadvantages.

- Multidisciplinary learning

By their nature, learning activities focused on 3D design and printing can span across several disciplines.

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Assessment and instructor feedback in 3D technology-based learning activities

Activities involving 3D would benefit from assessment approaches that focus not just on quantity but also on quality, and not just on end result but also on process and understanding. Especially in extracurricular activities, assessment should be designed so that it would not encroach on the students' freedom to experiment and take their model and project where they want to. Allowing students to make mistakes along the way may be just as important as ensuring that students succeed in the project. Generating a design that "does not work" or "cannot be printed" can be a powerful learning experience. At the same time, the demanding, time-consuming and sometimes openly frustrating nature of the 3D design and printing process is an unsettling reality for both students and teachers. Therefore, allowing too much time to be wasted on a model that could never work is also not a wise approach. Therefore, instructors need to find a good balance between allowing freedom and mistakes, and providing support and constructive feedback to avoid failure and disappointment. In view of the above, feedback and assessment should be provided during the whole process and not just at the end of the project. If students get feedback on their drafts (from the teacher or their peers), this will improve their learning and creative experience, and also the final results.

Engaging in 3D technology is a venture and an achievement in itself. Therefore, assessment should always go hand in hand with providing opportunities for showcasing learners' creations or with some other form of final performance. This would allow learners to take a step back and critically appraise their work, integrate feedback, and improve in the future. For motivated and successful creators and learners, having their results recognized and validated would also build confidence and provide motivation for further engagement.

With the above general guidelines in mind, we propose that assessment in student projects that integrate 3D technology should concentrate on:

- Concepts and techniques
- Attitude to learning and innovation
- Reflection and understanding
- Technical and artistic skills
- Responsibility demonstrated in the learning and creation process
- Effort, diligence and focus.

You may consider the following assessment guidance, adapted from the Sample Rubric for maker education by Lisa Yokana (https://www.edutopia.org/blog/creating-authentic-maker-education-rubric-lisa-yokana):

	Unsatisfactory	Competent	Proficient	Distinguished
Technique/ Concepts	The student's work lacks understanding of concepts, technology, materials and skills.	The student's work shows some understanding of concepts, technology, materials and skills.	The student's work reflects understanding of concepts, technology and materials, as well as use of skills discussed in class.	The student's work shows a mastery of skills and reflects a deep understanding of concepts, technology, and materials.
Attitude to learning and innovation	The student passively attempts to fulfil the assignment without	The student explores possible solutions and engages in innovative	The student explores multiple solutions. The	The student consistently displays willingness to try multiple solutions

	much thought or exploration of possibilities. The student refuses to explore more than one idea or solution.	thinking. The student has more than one idea and considers more than one solution, but does not pursue them.	student's innovative thinking develops and expands during the project.	and asks thought-provoking questions, leading to deeper, more distinctive results. The student fully explores multiple ideas and is willing to engage in iterations to observe the different results.
Reflection & understanding	The student shows little awareness of the learning process. The work does not demonstrate understanding of content and the underlying technology.	The student demonstrates some self-awareness. The work shows some understanding of content and the underlying technology, but the student cannot justify all decisions made.	The student shows self-awareness. The student's work demonstrates understanding of content and underlying technology, and most decisions are conscious and justified.	The student's work reflects a deep understanding of the complexities of the content and the underlying technology. Every decision is purposeful and thoughtful.
Technical skills and creativity	The student's work is messy, creativity is minimal. Technical skills are undeveloped and result in poor overall presentation.	The student's work is somewhat messy. Creativity and technical skills are somewhat underdeveloped and result in fair but not completely satisfactory overall presentation.	The student's work is neat, creativity and technical skills are sufficient overall, and the final result is satisfactory.	The student's work is impeccable and shows a lot of creativity, excellent technical skills, care and thoughtfulness in completing the final result.
Responsibility	The student's behaviour is characterized by frequent absences, tardiness, disrespect for classmates and teacher, disregard for equipment, software, materials and work.	The student is sometimes absent, tardy, or disrespectful. The student must be persuaded to be careful with the equipment, software, and the materials, and to commit to the work.	The student is most often present, on time, and respectful. The student usually handles the equipment, materials and software responsibly, and takes pride in work.	The student is consistently present, punctual, and respectful of classmates and teacher. The student demonstrates self-directed use of equipment, materials and software, and ownership of work.
Effort	The student's work is not completed in a satisfactory manner. The student shows minimal effort and does not use the class time effectively.	The student's work is complete but it lacks finishing touches or can be improved with a little effort. The student does just enough to meet the requirements.	The student has completed the work in an above average manner, yet more could have been done. The student needs to go one step further to achieve excellence.	The student has completed the work with excellence and has exceeded the teacher's expectations. The student exhibited exemplary commitment to the project.

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Practical techniques suitable for learning activities based on 3D technology

There are several practical techniques that fulfil the above criteria and are suitable for learning activities that aim to utilize 3D technology. They have different complexity levels and would take different amounts of time and effort on the part of both teachers and students.

Technique	Description	Complexity level
Hands-on exercise in 3D design or printing	Students work with 3D design software and/or 3D printers to create and/or print a physical object. The design can be very simple or a ready-made design can be used. A good approach is to redo as a 3D project a previous project/assignment that students have already completed. In this way, preliminary research can be omitted or would be easier, and students can probably better appreciate the advantages of 3D technology. Another useful approach is to move gradually from 2D to 3D. Students may be advised to sketch out their ideas on paper before they start designing in any 3D modelling software.	Easy to moderate, can be short-term (depending on the scope and the complexity of the model)
Project-based learning	Students are involved in a design challenge that requires them to use 3D design and printing skills to create an artefact according to requirements and specifications. The students work individually or as part of a team.	Complex, requires longer engagement
Problem-based learning	Students are presented with an authentic real-world problem that requires them to use 3D design and printing to create and test solutions.	Moderate to complex, requires longer engagement and multidisciplinary work
Storylining technique	Storylining involves using a narrative structure to organize and sequence the lessons so that the learning experiences are coherent from the students' perspective. During any given learning experience, students should understand how their activities are helping them to solve an overarching challenge (e.g. a design challenge) or to make progress on a scientific investigation. Each learning unit in the sequence should be motivated by questions about the overarching challenge or exploration. The technique is suitable for longer-term learning in the field of 3D technology. Starting at the beginning of the storyline, students are asking questions, defining problems, investigating, designing solutions or testing them. While performing any of these activities, they are generating more questions that they are motivated to address in the next unit in the learning sequence. In this way the students feel that they are constructing their own learning path and this path will be meaningful and coherent from their point of view. One of the easiest ways to implement the storylining technique in the context of 3D printing and modelling is to start the activity with a design challenge that the students need to	Complex, rather open-ended, requires longer engagement and multidisciplinary work

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	solve.	
Jigsaw learning activity	A jigsaw learning activity involves breaking up the learning exercise into smaller learning tasks and assigning each task to a different group or individual. Each group or individual becomes an expert on their assigned task and then transmits what has been learned to the rest of the group. In this way, the group as a whole learns all of the information and each individual has the opportunity to become an expert on one aspect of the topic.	Moderate to complex but can be achieved within a short period of time

- **Jigsaw learning activity proposal utilizing 3D technology**

Elements	Tips and proposals
Determine the learning objectives	*Use backward design to specify what you want students to know or do upon completing the learning activity, e.g. students learn about the structure of viruses, students learn the structure and functions of the human brain, students learn about the structure and behaviour of asteroids, etc.*
What 3D model(s) will be used (what will the model(s) represent)?	*E.g. a model of a hypothetical virus, a model of a human brain, a model of a space station antenna, a model of an asteroid, etc.*
How will the identified model(s) be used?	*E.g.* *- Students will study the model and label the elements* *- Students will assemble the model from its constituent parts* *- Students will disassemble the model and study each separate part* *- Students will test how the model works* *- Students will simulate how the model interacts with other objects* *- Students will design a model, print it, test is, re-design it if necessary and print again*
If readymade models will be used: Identify relevant 3D models that can be downloaded from an online repository *If students will design their own models:* Determine the requirements and constraints that the students should observe when designing the models (the type of the object, size, etc.)	*If readymade models will be used: see the available repositories in the "Additional resources" section* *If students will design their own models: see the "Teacher template for planning exercises involving the development of new 3D designs"*
If readymade models will be used: Consider the available options for 3D printing and how to finance it. *If students will design their own models:* Determine what software the	*If readymade models will be used, you need to find the optimal solution for printing the objects - e.g. using the school 3D printer, using an external service for printing, etc. If the school 3D printer will be used, consider scheduling issues and the cost of the materials.* *If students will design and print their own models, they could for example use Tinkercad and will be expected to work on their personal computers; or they could use Fusion 360 and work in the school computer lab. Details to consider are scheduling issues in the lab and whether the necessary software is already installed.*

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students can use, where it is available, and how they could print their designs	*For printing, the school computers and 3D printers may be used if available. In that case, a slicer software has to be installed on the school computers. If the school does not have a 3D printer, alternative solutions could be explored, such as a community makerspace, another school's lab, a university lab, etc.*
If readymade models will be used: Print the 3D models ahead of the activity	*You may want to use the "Teacher template for planning exercises involving printing 3D objects from existing designs".* *Consider that printing can be a time-consuming activity, especially if the models are big. Often, the print will fail for various reasons and should be re-printed, rescaled, more thoroughly re-designed or printed with support structures. It is important that the instructor be knowledgeable and experienced enough to choose the proper materials and technology, as well as to properly calibrate the printer in order to minimize waste of time and money. If necessary, consultation or collaboration with more experienced colleagues can be initiated.*
Specify the collaborative methods and the assessment	*A jigsaw activity will require that students are assigned to:* *- a "home" team where they start and to which they later return to present the final assignment,* *and* *- an "expert" team where they develop the final assignment on the basis of research and a 3D model.* *Thus, the student starts and ends as part of the "home" team, but works in the "expert" team in-between. Jigsaw enables each student of the "home" team to specialize in one aspect of the topic (with the help of the "expert" team), and then to transmit the knowledge to the "home" team.* *- The assessment can combine peer assessment within the "home" group (on the basis of an oral presentation) and a final written assignment evaluated by the instructor. Formative assessment based on assessing progress during the activity can be added to the mix.*
Design the activity in detail	*For a jigsaw activity:* *1. 3 topics/tasks with similar difficulty should be specified.* *2. The class is divided into 3 "home" teams. Each student is assigned to a "home" team.* *3. Students gather in "home" teams and are encouraged to choose a team name in order to form an identity. They are given the 3 topics/tasks and asked to nominate team members to 3 "expert" groups that will address these topics.* *4. The 3 "expert" groups are formed by members from the different "home" teams. The students leave the "home" team and join their "expert" team.* *5. If readymade models will be used, each "expert" group is provided with literature and resources, an outline, a relevant 3D model and instructions about how it should be used. If students will design their own models, the "expert" group is provided with literature and resources, as well as a clear document containing the requirements, specifications and constraints about the model that should be designed and printed.* *6. Each "expert" team is given an assignment or a project that they should complete (e.g. "research and design a model", "prepare an oral presentation in which you assemble or disassemble the model and provide details about each part", "explain and demonstrate the basic functions of the model", etc.). All "expert" group members work on the assignment and can split their responsibilities if they wish. The instructor should observe the work of the groups, provide instructions*

	and facilitate both learning and collaboration. *7. Upon completion of the assignments or projects, the "home" groups reassemble and the representatives from the different "expert" groups share what they have learned or present their assignment. Tasks, such as discussion or summarizing what was learned, may be given to the "home" teams. Peer assessment and review should be incorporated at this stage, as the "expert" groups receive feedback and/or evaluation through voting or grading by the others. The highest evaluated team can receive a reward, such as a bonus in the final grade on the written assignment that they will submit to the teacher.*
Schedule the activity	*Depending on the difficulty of the tasks and on whether it involves 3D design and printing by the students themselves, between 2 and 10 academic hours can be allotted to the activity. If the students will be designing their own 3D models, out-of-school work would likely need to be planned as they need to learn to use the software. Special preparatory training sessions on 3D design may also be needed.*

- **Teacher template for planning exercises involving the development of new 3D designs**

Name of the model/exercise	
Learning goals	
Required knowledge (prerequisites)	
Relevance to curriculum subjects	
Possible use of the model (e.g. prototype, use in the classroom to help students grasp a concept, etc.)	*Can this model be used in the classroom? Describe how.* *Is this model a prototype? What is the purpose of the prototype and the further uses?* *What are the benefits of using the model?*
Software that will be used for designing the model	
Necessary introductions / trainings	*E.g. training in Tinkercad*
Description of the model that is subject to this exercise	*What it should be, what it should represent, how it should function, how it should be used and other relevant descriptions*
Number of separate components of the model (if applicable)	
Minimal requirements for each separate component and the whole model (descriptive) *If students are given full freedom to design their own model, this section can be omitted.*	*Shape of each component* *Shape of the whole model* *Target dimensions of each component* *Target dimensions of the whole model* *Colour of the components (or the model)* *Texture of the components (or the model)*

Graphical representation of the model and its components - hand sketches, technical drawings or other graphical representation (use the same scale for all components!) *If students are given full freedom to design their own model, this section may be omitted.*	*Front view of each component* *Front view of the whole model* *Top view of each component* *Top view of the whole model* *Side view of each component* *Side view of the whole model*
Additional information about the exercise (if applicable)	
How will students be assessed?	*Assessment of final result* *Assessment of process*

❖ Teacher template for planning exercises involving printing 3D objects from existing designs

Name of the model/exercise	
Learning goals	
Required knowledge (prerequisites)	
Relevance to curriculum subjects	
Possible use of the model (e.g. prototype, use in the classroom to help students grasp a concept, etc.)	*Can this model be used in the classroom? Describe how* *Is this model a prototype? What is the purpose of the prototype and the further uses?* *What are the benefits of using the model?*
Necessary introductions / trainings	*E.g. training in using 3D printers; training about 3D printing materials, etc.*
3D printing technology that will be used	*FDM, SLA, SLS, etc.*
Material that will be used for printing	*Type (PLA, ABS, TPU, Nylon, PETG, etc.) and brand*
Specifications of the 3D printer	
Number of separate components (if applicable)	
Printing specifications for each separate component and/or the model as a whole	*Target dimensions of each component and/or the whole model* ▪ *Length* ▪ *Height* ▪ *Width* ▪ *Diameter* ▪ *Specific dimensions for complex forms* *Colour of the components (or the model)* *3D printer materials have colour, so unless the model will*

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	be subsequently painted, one colour has to be planned for each component. *If the component will be additionally painted instead (e.g. more colours per piece are necessary), specify the requirements for both painting and printing. Note that if the object will be painted, this will influence the printing process and the component should usually be initially printed in white.* *Texture of the components (or the model)*
Thickness and resistance to impact and stress	
Required quality and detail (accuracy, definition)	*Low, Medium, High*
Assembly type	*Clips, screws, gears, joints, hinges, pressure adjustment, cam-followers, etc.*
Post-processing requirements	
Additional information about the exercise (if applicable)	
How will students be assessed?	*Assessment of final result* *Assessment of process*

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References and additional resources

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Additional resources

❖ *Repositories with ready-made 3D models*

Printable 3D models by NASA: https://nasa3d.arc.nasa.gov/models/printable

The Smithsonian Institution's 3-D digitization portal: https://3d.si.edu/

National Institute of Health print exchange: https://3dprint.nih.gov/

A website sharing user-created digital design files: https://www.thingiverse.com

BioInteractive Resources: https://www.biointeractive.org/classroom-resources?search=&f%5B0%5D=resource_type%3A20

Unity Asset Store: https://assetstore.unity.com/categories/3d

Turbosquid Store: https://www.turbosquid.com/Search/3D-Models/free/unity

Sketchfab: https://www.sketchfab.com/

3DWarehouse: https://3dwarehouse.sketchup.com/unsupported/

CGTrader: https://www.cgtrader.com/3d-model

Tinkercad gallery: https://www.tinkercad.com/things

3D design resource: https://www.printables.com/model

A collection of simple Tinkercad projects: https://www.instructables.com/Tinkercad-Activities/

❖ *Guides and resources*

Official Guide to Tinkercad Classrooms: https://www.tinkercad.com/blog/official-guide-to-tinkercad-classrooms

How to Teach the Language of 3D Modeling and Design: https://www.instructables.com/How-to-Teach-the-Language-of-3D-Modeling-and-Desig/

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How to Bring Tinkercad Into Your Classroom: https://www.instructables.com/How-to-Bring-Tinkercad-Into-Your-Classroom/

Getting started with Tinkercad: https://www.tinkercad.com/learn/

Online video series with accessible hands-on learning experiences: https://www.youtube.com/playlist?list=PL6-XLLiQK8vG221svKhvUk7xc3h0SZ4fT

Free learning resources: https://www.makerspaces.com/250-makerspace-resources-free-ebook/

School Case Studies for using 3D design and printing: https://www.makersempire.com/category/school-case-study/

A detailed 3D Design Thinking Methodology: https://resources.finalsite.net/images/v1525445534/springlakeparkschoolsorg/ajwiefcx5g6dry0h1gsy/EssentialPlaybook.pdf; https://resources.finalsite.net/images/v1525445583/springlakeparkschoolsorg/p7segk1r3fut5fptiogx/EverythingPlaybook.pdf

A Beginner's Guide to Learning 3D Design & Illustration: https://dribbble.com/resources/learn-3d-design-illustration

How I taught myself 3D modeling in 100 days: https://medium.com/the-100-day-project/100-days-of-3d-4b28a514f3ac

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