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3D Print in education

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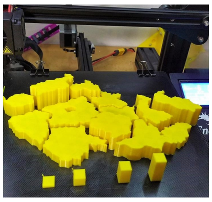
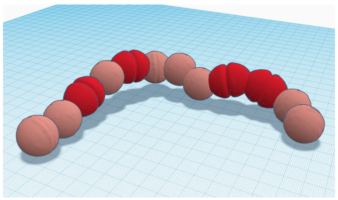
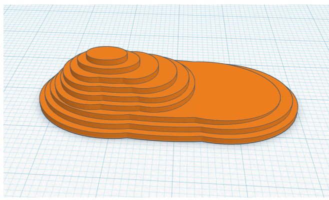

Abstract
3D printing has recently gained on popularity in various fields. However, to maximize the possibilities of the technology, specific skills are required. To prepare students for future employment, schools are trying to utilize 3D printing in teaching, but with little success, because there is no systematic approach. To solve this issue, a methodology for integration should be created, which covers technical, pedagogical and practical issues encountered by schools that tried to use 3D printing in their curriculum. For successful integration, it is necessary to provide complete lessons which can be immediately used in teaching. Those lessons are being made and five of them are already being tested. This article contains all required information to get started with 3D printing and its integration in primary and secondary schools. The methodology and the lessons make the technology more accessible, which could attract more schools to participate, possibly igniting discussion on the national level of integration.

Keywords: 3D print — Education — Lesson — Teaching aid — 3D print methodology

Supplementary Material: Lessons from Y Soft's Be3D Academy and MakerBot's Thingiverse Education

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1. Introduction

In the past few years, 3D printing became very popular. It quickly developed to an easy-to-access technology used by broader audience rather than top technological companies. However, to fully take advantage of this rapidly developing and widely used technology, design and technical skill is required to create usable models using complex computer programs, in addition to understanding the 3D printing technology itself. Schools are aware of this trend, trying to prepare their students for various aspects of life and job market requirements, which, according to the current development, will probably include the 3D modeling and printing skill in the near future [1].

In the past few years, several surveys regarding 3D print in education were conducted [2] [3] [4] and show clear shortcomings for successful integration. So far, there are no systematic approaches regarding 3D modeling and 3D printing – currently, schools that want to integrate 3D printing into their curriculum rely on their own independent activity (and the willingness of employed teachers to engage in out-of-the-ordinary areas of education). This is made even more difficult by inexperience of the teachers in all of 3D modeling, operating the 3D printer and using it in teaching. On top of that, there is not a sufficient amount of usable teaching materials to use with 3D printing.

Although there are already some technical solutions aimed directly at usage in school, they usually only cover the basics. The biggest gaps are usually lack of materials, methodology, guidance and other supportive tools, resulting in overwhelming the teachers, who have to *reinvent the wheel*, because they do not have sufficient experience. This requires enormous amount of time to research all the relevant information by itself, and on top of that the teacher needs to prepare teaching materials and consider how to integrate all the necessities into the curriculum. The solution needs to address 4 main problems:

1. **3D modeling and other ways to obtain models.** Comprehend available 3D modeling tools and show which ones are generally the best and should be focused on. Show possible alternative approaches to getting models.
2. **3D printing technology and usable materials.** Analyze and choose the proper 3D printing technology, which is suitable for educational environments. Considered factors should mainly be ease of use, printing capabilities and health safety. Provide list of available and suitable materials used in chosen technology with their positives and negatives.
3. **Practical aspects.** Circumstances and conditions such as space needed for printer and its operation, price of both the machine and printing itself, printer placement, accessibility and safety, required after-print processing and finishing jobs.
4. **Integration into education.** Provide lessons and teaching aids which can be immediately used in education. This requires pedagogical and didactic preparation, lesson plan, printing instructions and models to be printed or used as exemplars for modeling.

There are two aims of author's thesis: first, create a methodology for integration of 3D printing into education (with the focus on primary and secondary schools), and second, design lessons and teaching aids which can be immediately used in education. The solution is being created in cooperation with teachers from MUNI Faculty of Education[1], whose domain are the pedagogical parts of both the methodology and the lessons, whereas the technical and practical aspects of the created materials (both lessons and the methodology) are the topic and output of the thesis.

The technical part of the methodology provides solutions to the technical and practical problems of integration of 3D printing into education (with the focus on primary and secondary schools). Firstly, different ways to obtain 3D models (Section 2.1), including 3D modeling tools (Section 3) are analyzed. Secondly, 3D printing technologies are discussed and the most suitable one is presented (Section 4.1). List of usable printing materials is created with information about appropriate usage of each material (Section 4.2). Thirdly, remaining areas of technical part of 3D printing integration methodology are covered, mainly practical aspects, including printer settings and location, price and required finishing jobs (Section 5). Finally, as mentioned in the last item of the list, specific teaching aids and lessons are created, ready for immediate use in education (Section 6).

It is important that the technical level of the created methodology and lessons is deliberately reduced to allow easy comprehension, as the users of the materials will be teachers on primary and secondary schools, who might have trouble fully understanding technical text, especially on a topic they are not familiar with.

Resulting solution is not meant to compete with already existing solutions mentioned in the following section, but rather fill the obvious gaps in integration of 3D printing into education, uncovered by the surveys. It summarizes extensive materials, includes recommendations from teachers who already use 3D print in their teaching [5] and on top of that is to be available for free.

2. Background and Existing solutions

There is an overwhelming amount of 3D printable models available online. The models can be easily downloaded, optionally modified and then printed, or used as an exemplar for modeling the object manually.

2.1 Online 3D model databases

The biggest database of models is **MakerBot's Thingiverse**[2], providing almost two million 3D models by itself. Models here vary greatly with a wide range of topics covered. If you are looking for any 3D model, you will probably find it here if it exists.

Another portal is **PrusaPrinters**[3]. Among thousands of other models, there is a *Learning* section, providing models usable in education. Most of the models do not have any additional information about their usage in a lesson.

YouMagine[4] is also worth mentioning with more than eighteen thousand models and **NIH 3D print exchange**[5], which aims to provide scientifically accurate models as only few are available online. It contains mainly biology and medicine related models.

[1] https://www.ped.muni.cz/en

[2] https://www.thingiverse.com/

[3] https://www.prusaprinters.org/

[4] https://www.youmagine.com/

[5] https://3dprint.nih.gov/

Models in these databases are mostly free to download and use for non-commercial purposes, education included. Of course, there are many more portals on the Internet, but those often contain paid or copyrighted models, so there is a danger of infringing the intellectual property laws if used in education.

2.2 Existing solutions for 3D print integration

Probably the best, well-rounded solution, which addresses all four main problems, is **Y Soft's Be3D academy**[6]. It is an online collection of lessons prepared in every aspect – every lesson contains all necessary materials for immediate use: 3D model files, step-by-step tutorial, guidelines, print settings, appropriate print material information, lesson plan with curriculum alignment, video or a presentation to use in class and optionally a worksheet for students to fill.

Only a few lessons are free, the rest comes with a paid premium package. The whole solution contains one 3D printer, required software for printer operation, management suite for both 3D and regular printers (including an ID card reader), and on top of that offers online training in using the provided 3D printer.

Unfortunately, there are currently only 40 lessons available which might not be enough to justify the investment, but there are more lessons on the way. Also, covered subjects are mainly STEAM[7] and occasionally humanities, with some subjects not covered by a single lesson.

Another solution is **MakerBot's Thingiverse Education**[8] tab. It contains various lessons usable in all levels of education, from first grade to university. Multiple models are grouped into lessons with in-depth descriptions, which contain design process, print settings, skills learned, lesson plan with activities, presumed duration of the prepared lesson and necessary preparation. There are often links to additional materials, like video with explanation or walkthrough and ideas for follow-up activities.

Covered subjects are again mainly STEAM, but there are more lessons covering humanities when compared to Be3D academy. Interestingly, there is also a Special Ed category, in which lessons focus on trying to fulfill the extraordinary needs of students addressing their individual differences, e.g., aid for learning braille. In addition, resources like webinars are available on MakerBot's website[9].

[6] https://be3dacademy.ysoft.com/
[7] Science, Technology, Engineering, Art, Math
[8] https://www.thingiverse.com/education/
[9] https://www.makerbot.com/education/

3. 3D Modeling programs

For the purpose of this article, technical details like model types, representation and processes are not going to be mentioned, as the focus is on the modeling programs, which can be used in schools. The only requirement is that the program must be able to export STL files, which can be used in almost every *slicer* - a program that converts the model to instructions for the specific 3D printer.

One of the most popular modeling software is **Blender**[10]. It is a free, cross-platform, open-source program that offers a whole suit of tools for creating complex computer graphics, including video editing, visual effects, animations, simulation and even game creation.

Blender is very efficient, and regarding 3D modeling, there are seemingly unlimited possibilities. On the contrary, users often do not know how to take advantage of the provided tools. As Blender tries to cover all the different aspects of creating 3D computer graphics, the program may be too complex. Beginners find it chaotic, but when an experienced user is using Blender, it is one of the fastest tools for 3D model creation. Simply put, *"Blender is a Swiss army knife among 3D modeling applications"* [6].

Autodesk's **Fusion360**[11] is a great tool with lots of tutorials online and is free for non-commercial use, education included. Unfortunately, it does not have great language support, for example it cannot be switched into the Czech language[12], which might hinder the usage in Czech schools.

The model creation process and user interface is very similar to industry standard software. Compared to Blender, it is way more intuitive, well-organized and definitely more user- and beginner-friendly, but it is harder to create organic-looking, irregular shapes.

While both Blender and Fusion360 are desktop applications, Autodesk's **TinkerCAD**[13] takes another step to simplicity and accessibility, as it runs in any modern internet browser. It is a great and intuitive tool well suited for beginners.

Model creation is different from other programs, yet very simple: Models are created by combining primitive shapes such as cubes, spheres and cones (as shown in Figure 1). Those shapes can be both solid, creating the body of the model, or holes, which

[10] https://www.blender.org/
[11] https://www.autodesk.com/fusion-360/
[12] Although there is a Czech localization for Fusion 360, it is paid for and needs to be installed separately as a plugin. Available from https://fusioncesky.cz/ with more details.
[13] https://www.tinkercad.com/

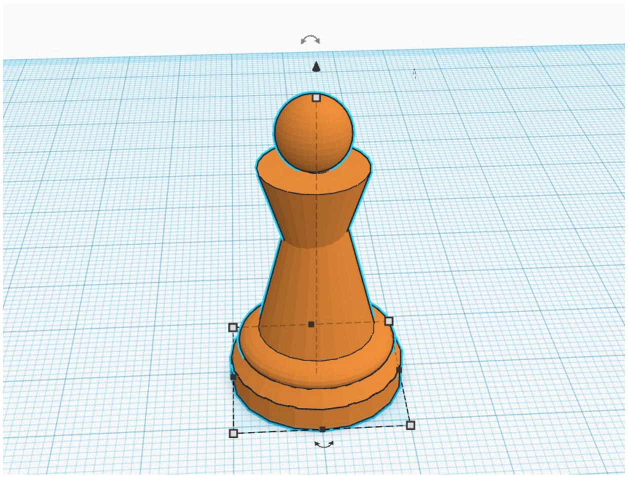

Figure 1. A chess pawn created in TinkerCAD by combining cones, spheres and cylinders.

are used to create cuts into solid objects. There is a decently sized selection of primitive shapes, including organic shapes and text.

Even though the application is missing advanced functions, it can import and edit STL files, meaning complex models can be downloaded from one of the online databases or previously created in some other program. This approach can become very practical in education, as the model, which is difficult to create, can be previously prepared by a teacher or shipped as a part of a lesson.

Lastly, **SolidWorks**[14] is a paid suite of programs. For the purposes of 3D modeling by itself, it does not really offer much more than Fusion360. Point is, that some schools with special focus on industry[15] use SolidWorks or similar programs for other reasons – designing a component, blueprinting, exporting as CNC machine instructions etc. Students that are experienced with the whole suite can also use it for the creation of 3D printable models. On top of that, they are offered 3D printing as another option in the manufacturing process, instead of creating the component on a machine or manually, which can save both time and resources.

In conclusion, TinkerCAD seems to be the obvious best choice for beginners, as it is a very efficient tool for creating rather simpler models. For more complicated models, which need to be precise, Fusion360 or SolidWorks is a great choice, while for sculpting and modeling organic shapes, Blender is the go-to tool.

4. Printing technologies and materials

There is a great variety of different 3D printing technologies and materials used in each of them. For the purpose of utilization in education, it is necessary to choose machines with good-enough print quality and speed. Also, the possibility of self-service printing without professional supervision should be considered. But most importantly, safety while manipulating the printer or used material is the top priority.

4.1 3D printing technologies

Currently, the most popular technology used for 3D printing is **FFF (Fused Filament Fabrication)**. The principle is that prefabricated thermoplastic material is deposited layer-by-layer on top of each other. FFF offers an excellent price to performance ratio, printer operation is simple and quick and the print quality is sufficient for hobbyists and schools. Most importantly, operating the machine is safe, both mechanically and regarding usable materials. All of this makes FFF considerably the best general choice for primary and secondary schools.

Another popular technology is **SLA (Stereolithography)**. Compared to FFF, SLA has better print quality at the cost of higher price of both the machine and material. Essentially, a liquid resin is cured with a UV light (mostly laser). Safety precautions need to be taken, as the liquid resins are toxic – users should prevent the resin from touching the skin and inhaling the vapors, making it not a good option for educational purposes unless sealed as a whole and well ventilated [6].

Lastly, using **SLS (Selective Laser Sintering)**, objects are created by selectively melting and resolidifying powdered material by a laser beam. This principle is often used in sintering metal or ceramic powders. Compared to FFF and SLA, it is significantly more expensive, and similarly to SLA, not a great fit for educational environments due to price, complexity and speed [7].

There are many more other technologies, but they are usually not suitable for use in schools due to various factors, mainly price, health safety, space requirements and complexity of operation [8].

4.2 Materials

Materials are discussed from the perspective of using the FFF technology, as the positives heavily outweigh the negatives. Generally suitable and versatile material is **PLA (Polylactic acid)**, being flexible, hard and durable like other plastics. It is biodegradable, made from renewable sources and reasonably priced. On top of that, it is one of the easiest materials to print with. On the other hand, it is not very heat resistant, as it starts to soften around 60 °C [6]. During the printing process, no harmful fumes are produced, making it a very good choice for use in schools.

[14] https://www.solidworks.com/

[15] E.g., High school with focus on industry Sokolská, Brno

In situations where PLA is not the ideal material, **ABS (Acrylonitrile Butadiene Styrene)** or its successor **ASA (Acrylonitrile Styrene Acrylate)** comes in. It has better flexibility and both thermal and mechanical resistance. There are many versions with different additives, enhancing or adding new properties (e.g., ABSi with translucent effect). Objects are more difficult to print because they tend to bend and wrap during printing. Importantly, harmful vapors are produced during the printing process [6].

Another usable materials are **PETG (polyethylenterephtalateglycol)** – recycled PET with similar properties to PLA, flexible materials from the group of Thermoplastic elastomers often called **Elasto** or **Flex** as a substitution for rubber, or **PP (Polypropylene)** and **Nylon**, which are tough and friction resistant, but very hard to print.

5. Practical aspects of integration

Various factors play a role in successful integration of 3D printing into education. Printer placement and accessibility is crucial for its use. According to the experience of teachers who successfully integrated 3D printing into teaching [4] [5], and research provided by Y Soft [3], the optimal variant is a classroom where the number of printers is the same as the number of students (per lesson). This way, all students go through the complete process to gain experience. The problem is, that small number of printers is pretty common as a testing deployment.

Another issue with placement is the required access to electricity, network and being safe both during the printing process and from unauthorized manipulation. Also when using specific materials, the printer may need constant temperature to prevent product deformation. At the same time, the printer should be accessible to allow personal prints to maximize its utilization. The opportunity to interact with the printer can further stimulate the interest of students.

While it is hard to meet all these requirements, it is certainly not impossible. Placing a printer in a public space may seem dangerous, but printers that are fully covered eliminate the risk, while also providing constant temperature and humidity. These covered models often provide measures against unauthorized manipulation during printing (automatic lock) and an access control system using e.g., smart cards [9].

A huge factor for many schools is the price, both initial investment into the printer and regular cost of material and possible required maintenance. If the teaching materials or lessons do not come in the bundle with the printer, it is another item on the list of expenses. As previously discussed in Section 4.1, the FFF technology, together with materials like PLA or PETG are perfect in their price to performance ratio.

The printed product often needs some finishing work, such as sanding or painting. There is no general solution, but this need should be taken into consideration. Some suggestions might be: having the painting supplies available in the art department, sanding papers in the workroom, etc [10].

6. Use in education

As foreshadowed, more systematic approach is required. One part of the solution, a methodology for integrating 3D print into education is currently emerging, covering the didactic, pedagogical, technical and practical areas. Key topics of the technical and practical part, which is one of the results of the thesis, include:

- 3D modeling and other ways to obtain models
- Comparison of available 3D printing technologies from the perspective of health safety, ease of use, printing capabilities, print speed and quality
- Selection of the most suitable technology for use in schools
- Analysis of available materials for the selected technology
- 3D printer placement and accessibility
- Price (both initial and regular into materials and maintenance)
- Finishing jobs

These topics are discussed in previous chapters. Thanks to the methodology containing necessary information, it is possible to create entirely new types of teaching aids and approaches, as students are not only able to work with teaching aids in class, but actively participate in their creation and are *learning by doing*.

The educational part will summarize available materials, present how to systematically involve 3D printing in the curriculum and provide some basic useful lessons. Additionally, barriers, general issues and its solutions, basic procedures and recommendations for systematic implementation will be presented in the context of individual grades of primary and secondary school. It will also contain information about cross-subject integration. Of course, there will be implementation examples of mentioned approaches and tools.

Besides the methodology, lessons which can be immediately used are being created. The lessons consist of the following parts: instructions for 3D printing, lesson plan, pedagogical and didactic information *(what*

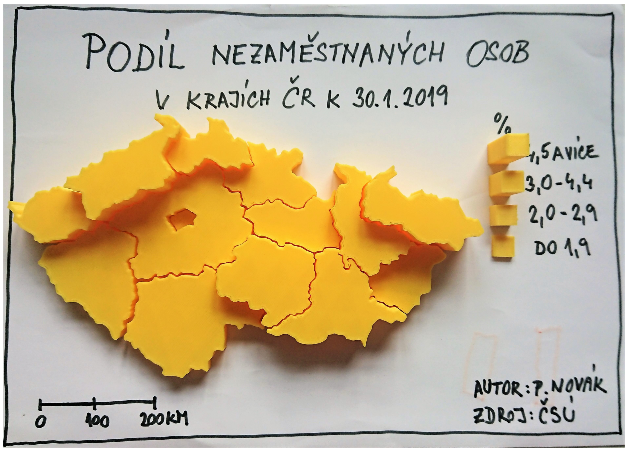

Figure 2. Final product of the geography lesson. Photo by Mgr. Darina Mísařová, Ph.D., who also created the pedagogical part of the lesson.

and how will the student learn in this lesson?), presentation or video to use in class, prepared 3D models to print or modify and optionally worksheets for students. In case of modeling or modifying delivered model, a step-by-step tutorial is needed. Currently, there are five lessons that are already being tested, with more in the making.

As there are proportionally way more lessons available for STEAM subjects, one of the lessons, created in cooperation with Mgr. Darina Mísařová, Ph.D. from Faculty of Education, is to be used in geography in the Czech Republic. In this lesson, intended for 8th and 9th grade, students work with map of the country divided into regions. They first research relevant data for the set topic (in this example unemployment rate, as shown in Figure 2). Secondly, they either model the districts or use prepared models delivered with the lesson. Thirdly, by setting the correct height of each region illustrate the set topic – e.g., districts with higher unemployment rate will be higher than the ones with lower rate.

This height-map is then printed and completed with other composite elements, such as map name, scale, map legend and imprint. Finally, SWOT[16] analysis is performed and the causes and consequences of the distribution of the phenomenon are discussed. During the discussion, students are motivated to come up with solutions to problems caused by this distribution.

Modifications of this lesson could be using different topic (population density, urbanization rate, average wage, GDP, etc.) or alternative administrative units (whole countries, or only districts) – currently, states of USA and Europe can be easily generated using TinkerCAD, allowing for easy use in this lesson.

[16]Strengths, Weaknesses, Opportunities, Threats

Based on experience with integrating 3D printing in schools [4], number and quality of the lessons is crucial for their adoption. Teachers simply do not have the time or space to create new ones or greatly modify existing ones themselves. That is why every lesson is being tested by both technical and pedagogical experts, composed of teachers both inexperienced and experienced with 3D printing and its use in teaching, IT and 3D print experts from Y Soft and pedagogical and technical experts from Tablet Academy[17], a partner of Y Soft. This thorough testing in multiple cycles is hoped to remove all possible issues, such as non-printable model, vague description of aims, activities and tasks in the lesson and potentially provide new ideas for new lessons.

7. Conclusions

By using 3D printer in schools, students are preparing for possible future labor market requirements (especially in the industry). But most importantly, students are able to not only work *with* teaching aids, but actively participate in their creation and *learn by doing*.

Based on the performed analysis and previously conducted surveys [2] [3] [4], a systematic approach is necessary. As a result, a methodology for 3D print integration is emerging and its key points are being discussed in this article. When choosing the technology to use in school, Fused Filament Fabrication is selected for its safety, performance and price, together with the PLA or PETG printing material for their versatility and ease of printing.

To maximize the potential of the technology, complete lessons ready for immediate use in teaching are being created, five of which are already being tested by experienced professionals. The lessons are crucial in the whole process, and need to be of a good quality, both technically and pedagogically, containing prepared models, instructions for modeling and printing, lesson plan, pedagogical information and good presentation material. Finally, one created lesson is described in detail.

This article contains all the necessary information to get started with 3D printing and its integration into primary and secondary schools. With more lessons being created, it is believed to make the technology more accessible and to attract more motivated teachers and 3D printing enthusiasts to allow its adoption in more educational institutions, which could help igniting a discussion on the national or even international level of integration.

[17]https://tablet-academy.com/

Acknowledgements

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