Strategy of Education on Materials for Students

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Abstract

The properties of products do not only depend on the ingredients of the raw materials but on the entire production process as well. This is why the education of engineers should cover both, material science and manufacturing - with a focus on its interdependence.

Traditionally, raw materials are made independently from the latter manufacturing. Consequently, the product properties do not wary too much as long as certain production rules are obeyed.

New production technologies such as Additive Manufacturing (AM/3D Printing) act as a game changer, mainly because the properties of the final part result not just from the ingredients but from the build parameters applied to the printer. Another big influence is time. Traditionally, materials are mainly obtained from all kinds of mixing processes accompanied by long term heating and cooling while AM-processes make the material in situ which means in seconds or even in fractions of seconds.

Our approach to materials education therefore integrates AM. The concept is to simultaneously teach manufacturing technology including the construction/operation of a 3D printer capable to process a wide range of thermoplastic materials including material science using the printer.

In our concept in the beginner-courses demonstrate the AM-process and the behavior of some sample materials while printed. Next, students are forced to interact by assembly of the printers and operation for various materials. Doing so, they are for the first time confronted with the structure and meaning of parameter sets. Results are evaluated in comparison to traditional produced ones by dimensional measuring, weighting, tensile test and analysis of scan data.

Keywords: *3D Printing, Additive Manufacturing (AM), Teaching AM, STEM*

1. Introduction

Additive Manufacturing (AM) is the worldwide term for the layer-based technology, which became known as Rapid Prototyping in the late 1980s. Additive Manufacturing, 3D Printing and Desktop Manufacturing are today identical names for those new production technologies that based on a geometrical representation creates physical objects by successive addition of material [1] and which are said to be the basis of an upcoming further industrial revolution [2]. They are suitable to accelerate the product development process by a fast availability of complex prototypes and to improve their quality. Additive Manufacturing processes offer the unique possibility to build complex devices in a resource-efficient way with for example filigree structures and integrated functionalities. It is not only an indispensable tool for direct digital production of models and prototypes, but also a manufacturing process for the production of end products of plastic, ceramics and metal as well as for the production of tools, gauges and moulds.

Additive Manufacturing also enables us to produce finished products directly and independently of the batch size. Thus, they actually mark a revolution in production technology: The conversion from a production technology to the production of large series of equal parts to a serial production of different parts, be it individual parts, any batches or even mixtures thereof.

Everyone involved in design and production, but also in strategic planning, should know so much about the AM technology that a qualified assessment and selection can be made. The application fields of the technology are broad: aerospace, automotive, tool building, medical and electronic engineering, furniture industry, architecture and design [3].

2. Additive Manufacturing in Education on Materials

3D printers are a fascinating tool for teaching and education. More and more universities are integrating not just the topic AM but 3D printers as a tool. Several years ago, Szulzyk-Cieplak et al. [4] reported that 3D printing can directly support the teaching process. From the idea to the printed part: Keeping the previously virtually created file printed in your hand, motivates students and promotes understanding of the creation process and enhances students´ involvement in class. Through 3D printing, students can translate their ideas directly into reality, and spatial imagination is promoted [4].

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Usually, in the early years, teaching begins with physical objects and later deals with abstract, virtual 3D models. 3D printing allows a reversal: from drawing (3D CAD) to the physical object. It is now possible to directly link the two processes during the learning phase. This will stimulate creativity and enhance imagination [5].
The involvement of 3D printing in education and training is growing rapidly. Some examples are intended to outline the direction being taken in this developing field.
The fact that nowadays a whole range of affordable 3D printers are available, so that children can also get access to this technology, presents a challenge to educate the young students to use 3D printers. Eisenberg points out that the education process is a complex integration of several fields of design and manufacturing, which is not to be handled intuitively [6].
In its 2013 study, the "Department for Education" highlights the issue of 3D printing in schools and its integration into the curriculum, with the aim of improving the teaching of STEM and general design projects [6]. "Feedback from this exploratory project confirms that 3D printers have significant potential as a teaching resource and supporting tool and can have a positive impact on pupil engagement and learning if schools can master how to use the printers in an effective and meaningful way" [7].
In Slavkovsky´s [8] thesis: ""Feasibility Study for Teaching Geometry and Other Topics Using Three-Dimensional Printers" she focuses on the implementation and use of 3D printers as an illustrative tool in mathematics education. She predicts that 3D printers today and in the future will be used even more by students to improve their studies and understanding in mathematics.
Various groups are currently working on how to integrate the future technology into teaching: There are good approaches and best practice examples. However, 3D printing technology is only firmly anchored in curricula in exceptional cases.
Additive Manufacturing is a typical cross section technology and education in the field of AM has to include a lot of different disciplines e.g. engineering design, mechanics, electrical engineering, IT, control engineering, programming and material sciences. In addition, education in the field of AM has to have a high amount of practical activity to be interdisciplinary.
The new technology also enables new, interdisciplinary teaching concepts to be implemented and realized.

3. Teaching Approach

The AM technology can be excellently used as an instrument to awaken intrinsic motivation of students and to inspire them for STEM, in general and for material sciences in particular. In general, interdisciplinary teaching concepts have been firmly anchored in teaching for years and show general success in the transfer of knowledge. AM is a typical cross-section technology and therefore offers great potential to be integrated into interdisciplinary teaching.
As pointed out, our approach to materials education is based on Additive Manufacturing, due to the fact that the properties of products do not only depend on the ingredients of the raw material but on the entire production process as well. Education of not only Engineers should cover both: material sciences and manufacturing with a focus on its interdependence. It is like cooking: the same ingredients may result in a different meal if details of the process change.

4. Interdisciplinary Teaching Concept

Our goal is to simultaneously teach manufacturing technology including the construction/operation of a 3D printer and material science using the printer.
In an elaborated one-semester course (undergraduate – Bachelor, University), participants are taught skills in the field of mechanical engineering and material sciences. Not only the combination of two disciplines, but also a balanced relationship between theory and practice (hands on) will arouse the intrinsic motivation of the participants.
The teaching unit consists of different modules, which are all self-contained. Depending on the target group and the desired learning outcomes, the modules can be combined. There are three types of modules: modules that consist mainly of lectures with small slots for discussion and question rounds. In lectures knowledge is theoretically taught. Modules in which purely practical course contents are taught, we call henceforth workshop (hands on) and a mixture of a lecture and a workshop a tutorial.

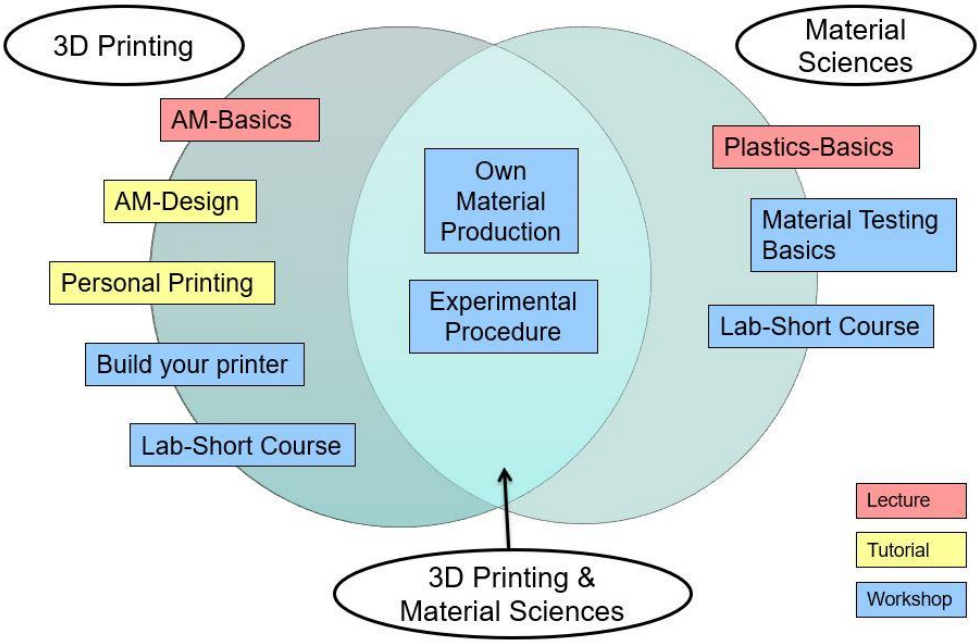

Fig. 1: Interdisciplinary teaching concept: Teaching Material Sciences and 3D Printing

We subdivide the modules into the categories "3D Printing", "Material Sciences" and "3D Printing and Material Sciences". The first two categories can be offered and booked completely independently, individually or parallel. Requirement for the third category is the successful participation in the modules of the first two categories.

3D Printing	Learning Outcomes
AM-Basics (Lecture)	Participants… • can explain the terms rapid prototyping, rapid manufacturing and rapid tooling • can explain the different layer manufacturing methods (5 process families) and distinguishe them from conventional processes • can explain the advantages and disadvantages of each AM-method, evaluate them and differentiate the application from each other.
AM-Design (Tutorial)	Participants… • can explain the data flow and the whole process chain of additive manufacturing and know the different file formats (CAD and AM) with their advantages and disadvantages • can delineate the conventional design from the design for AM • can explain the design and construction rules that should be used to produce a quality component • …
Personal Printing and Software (Tutorial)	Participants… • can distinguish and classify the market in the Personal Printing sector • have master knowledge of new business models that have evolved in recent years • master the process chain: from the idea to the final product • know how to generate printable files (through scanning / cloud printing / designing...) • can explain the different AM software for Personal Printing (slicer, host and firmware) • …
Build your own printer (Workshop)	Participants… • can build their own printer • understand the controlling and electronics of the printer • can weigh the pros and cons of the various software programs for 3D printers and choose the ones most suitable for them • can operate the printer, design their own ideas and print them
Lab-Short course (Workshop)	Participants… • get in touch with different AM machines (Industry and Personal Printer) • Assess the quality of different AM-manufactured components • get an insight into the postprocessing

Tab. 1: Overview of the module contents of the category: 3D Printing

Table 1 shows an overview of the module contents, learning outcomes, of the five modules of the category "3D Printing".

Material Sciences	Content
Plastics-Basics (Lecture)	• General features and applications • Formation of polymer chains • Bonding forces in polymers • Spatial arrangement of chain molecules • Classification of plastics • Crystalline and amorphous molecular arrangements • deformation properties • Non-polymeric additives in thermoplastics • Designations of plastics • composites

Material Testing (Workshop)	• Mechanical properties - language
	  ○ Force (or load) vs. stress
	  ○ Elasticity and plasticity
	• Mechanical properties testing
	  ○ Materials strength testing
	  ○ Stress-stain diagram
	  ○ Material bending testing

Lab-Short course (Workshop)	Participants… • get in touch with different Plastic processing machines in a lab tour • Assess the quality of different manufactured components • Working on an injection molding machine • get an insight into the postprocessing • manufacture their own samples

Tab. 2: Overview of the module contents of the category: Material Sciences

The prerequisite for participating in the modules of the third category is the successful completion of the first two categories.

3D Printing & Material Sciences - Content	
Own material production (Workshop)	• Introduction: Resource Efficiency and Sustainability • Shredding of misprints or excess (3D Printer) • Analysis of the granules • Filament production by extrusion • 3D print of the produced material • Test and evaluation of sample parts

Experimental procedure (Workshop)	• Printing sample parts with different materials and different printing parameters
	  ○ Tension rods
	  ○ Bending test samples
	• Comparison and Evaluation of 3D printed and injection molded samples

Tab. 3: Overview of the module contents of the category: 3D Printing and Material Sciences

5. Conclusion

Our approach to materials education integrates 3D Printing / Additive Manufacturing. Our elaborated teaching concept is to simultaneously teach manufacturing technology including the construction/operation of a 3D printer capable to process a wide range of thermoplastic materials including material science using the printer. Our concept is divided into 3 categories: 5 modules "3D Printing", 3 modules "Material Science" and 2 modules "3D Printing and Material Science".
On the one hand our beginner-course demonstrates the AM-process and the behavior of some sample materials while printed. Next, students are forced to interact by assembly of the printers and operation for various materials. Doing so, they are for the first time confronted with the structure and meaning of

parameter sets. On the other hand the participants are taught all basics of material science (plastics) and material testing.
Results are evaluated in comparison to traditional produced ones by dimensional measuring, weighting, tensile test and analysis of scan data.

- Our courses demonstrate the AM-process and the behaviour of sample material parts
- Students are integrated by assembly and operation of the printers for various materials and parameter sets
- Results are evaluated in comparison to traditional produced ones by dimensional measuring, tensile tests and analysis of the scan data...
- Our students deal with materials and their behaviour
- Students are integrated by producing their own material **and** their own sample parts
- In addition: the theme of sustainability is promoted

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