Enhancing EU Employability
by Adult Training in 3D Printing

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Guidelines on the use of 3D printing in Adult Education

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Revision History

Revision	Date	Author/Organisation	Description
1.0	04/03/2018	Emanuel Balzan /MECB	Draft of guidelines
1.1	05/03/2018	Philip Farrugia /MECN	Revision of draft
1.2	06/03/2018	Emanuel Balzan /MECB	Correction

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1.0 Background

With increasing breakthroughs in the ability of manufacturing artefacts of varying complexity, size and material, the usage of three-Dimensional (3D) printed parts and 3D Printing (3DP) per se, is becoming more frequent. In the age in which Europe is experiencing the 4th Industrial Revolution (or Industry 4.0), entire industries are undergoing complete transformation in which the available technologies are changing the way by which certain tasks used to be performed. In the last decade, 3DP has become the preferred manufacturing method for individuals, SMEs and large organisations. Subsequently, many jobs are threatened by redundancy while others require that personnel change and adapt their skills as necessary. Moreover, new vacancies are being created in several sectors such as architecture, medical and engineering industries while repetitive jobs in administrative, manufacturing, entertainment and construction industries are declining[1]. Whilst 3D printing is a necessity in many sectors that involve the exploration of new ideas, prototyping or where parts are required urgently or due to tight budget constraints, adults around the world lack the skills needed to comprehend and utilise 3DP technology even though they have years of experience with other technologies[2]. As a result, this shortage in talent coupled with high skills instability are causing recruitment problems in businesses which will worsen in the coming years. To mitigate this problem and get individuals up to speed with today's and upcoming challenges, it is necessary to reskill and educate the workforce such that they take new challenges and rewarding positions.

Within this context, the overall goal of this project is to equip EU adults with competence in 3D-P technology. Specifically, this KA2 is precisely concerned with developing a training material to help Adult trainers to attract, reach out and assist adult learners to catch up with the 21st Century digital skills of 3D-Printing. Additionally, throughout this training, adults will gain ICT, engineering and transversal technological knowledge and skills,

Through the project's deliverables, both adult trainers and adult learners will gain from it, irrespective of their educational background or nature of their current job. Before developing the training resources, it is important for the project partners to structure their views on the outcomes of the project such that to allow adults to take advantage on the 3D printing revolution. This report will provide essential information for the subsequent Intellectual Outputs of the project and, for anybody interested in using 3DP in Adult Education (AE).

[1] The Future of Jobs report - World Economic Forum (http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf)

[2] The Future of Work: Jobs and Skils in 2030 (https://www.oitcinterfor.org/sites/default/files/file_publicacion/thefutureofwork.pdf)

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As detailed in the following sections of the report, based on the partners' experience and on preliminary studies carried out, the guidelines have been outlined. Section 2 discloses the target groups involved and how this training programme is different from similar programmes. Based on previous studies, Section 3 discusses the desirable characteristics for the guidelines and by which the training needs of adults are understood. These characteristics are used as criteria by which the consortium's experience was evaluated. Section 4 lists a glossary of terms that will be used in the training material and the guidelines for teaching the target groups. Section 5 focuses on the critical implementation actions for generating and testing the training material, whereas Section 6 will briefly mention the different case study areas that IO2 will focus. The last section outlines key conclusions and recommendations for future work.

Ultimately, these guidelines will be used as a foundation for an original curriculum targeted at engaging both adult learners and adult trainers to learn 3DP, and then to develop the course material which is to be translated into e-learning content in different languages. Finally, the training material will be made openly available to the target groups across Europe.

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2.0 Target Groups and the Project's Innovative Characterises

At this stage it is important to clearly specify the Target Groups (TG) that this training material will be aimed for. The following three target groups were identified:

TG1: the primary TG are EU Adult trainers as these will be able to exploit the 3D-HELP training toolbox to help adult learners acquire skills on 3DP technology. It is not uncommon that trainers per se are not familiar to a topic which they need to teach to others. Thus, it is important to provide adequate resources and references by which the trainer becomes knowledgeable about the subject and eventually be able to teach the subject. On the other hand, experienced trainers might need additional material by which s/he can better transfer the knowledge. Typical adult trainers are:

- Private or public educational institutes that provide training in their own buildings or visit external organisations to provide training to their employees.

TG2: the secondary TG consists of Adult learners that need a second chance of catching up 3D-P technology. There is a wide audience in Europe (44% of adult population[3]) that have a limited digital skills, including knowledge about 3D Printing. Such people Such TG has missed the opportunity to learn about 3D-P at school but can now be taught through the AE training programme. Younger people might have a limited knowledge about 3D-P but did not pursue a career in technology

TG3: the third TG consists of stakeholders related to the AE sector including professionals, employers, training providers, representatives from cultures and social fields, policy makers and managers from a business perspective that can influence the direction of adult training.

From the preliminary observations, several lacunas and opportunities were discovered in each of the partner's countries about 3D-P and education. The problem is common across all the countries in Europe and around the globe. The training toolbox will be developed to meet the necessary skills required by researchers, labourers, AE systems and trainers alike, and prepare them to this emergent technology.

[3] Digital opportunities for Europe (https://ec.europa.eu/digital-single-market/en/news/digital-opportunities-europe-digital-skills-and-jobs-coalition-conference)

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3.0 Desirable Characteristics of the Guidelines

To understand the requirements for an effective training curriculum, a questionnaire was drawn and circulated to all the partners. The questionnaire (see Appendix) lists a set of criteria or characteristics and the requirements for course content and training approach for both the adult trainers and learners. Each criterion and aspect of training, along with the obtained results are explained in the subsequent sections.

3.1 Definitions

In **question 1**, the partners were asked to rank the importance of the criteria. The criteria are listed and defined in Table 1.

Table 1: Criteria definition for question 1

Criteria	Definition
Course Content	The course content refers to the topics and information to be included in the training material.
Course learning style	The learning style dictate how the training material will be conveyed to the adult educators and adult learners. It is widely known that adults are different from undergraduate adults/teenagers and thus, learn differently.
Clarity	Clarity refers to how the course content is communicated preventing misunderstanding. This allow learners to get knowledgeable with the topics fast and without uncertainties.
Course Language	Course language refers to the actual language used (e.g. English, Romanian, etc.).
Learning Environment	The learning environment refers to the physical or virtual locations used in which the training material will be delivered.
Relevance	Relevance refers to the importance that the training material be closely connected or appropriate to the audience.

The **second question** asked the partners whether the training material for trainers should be different from that of adult learners. There are no terms to be defined for this question.

In **question 3**, the partners were requested to rank the importance of topics to be included in the training material for trainers or learners having

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different levels of experience, that is, beginners, intermediate and advance individuals. Table 2 describes each topic.

Table 2: Topic definition for question 3

Topic	Description
3D Printing theory	3D Printing theory refers to the process (also referred to as Additive Manufacturing) by which objects are created from computer files, known as 3D CAD models. The theory includes, not limited to, the advantages and disadvantages of the technology, how it works (the actual basic process), usage restrictions, applications
3D Printing Materials	Nowadays, many different materials can be used for 3D printing, including: ABS, PLA (Polylactic acid), nylon (polyamide), epoxy resins, silver, steel, wax, titanium.
3D Printing Processes	Different 3D printing processes exist which permit of differently size artefacts and from different materials. Advanced printing techniques allow for printing of multi-coloured objects
3D Printing Resources	3D Printing resources refers to online available 3D CAD models which can be downloaded, edited and 3D-printed.
3D Modelling	3D modelling is the process of creating 3D CAD models on a computer.
Case Studies	A case study is an instance or process or record of something that is analysed to illustrate a principle.
Purchasing a printer	Like any other technological gadget, 3D printers have several specs and parameters. This module gives insight about the special considerations needed to be made before purchasing a printer.

The **last question** asked the users to rank the way the training material must be delivered to different levels (beginner, intermediate and advance) of adult trainers/learners (see Table 3).

Table 3: Delivery style definition for question 4

Delivery Style	Description
Reading step-by-step instructions	Instructions that have simple notes and explain the theory step-by-step. The instructions can take the form of a book, presentation, video, etc.
Listening to a lecture/presentation	Training is delivered by allowing trainers/learners listen to a lecture delivered by a professional. Notes shall be taken during lecture and/or supplied by the instructor.

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One-to- one coaching/mentoring	Such method of training gives full attention to the trainee allowing more time to be dedicated to him/her. In contrast to group discussions or lecture, such method tends to be less diverse since only the interest of one learner is considered.
Watching a 'how to' video	A picture is worth a thousand words, but a video is worth 1.8 million words per minute. Video boosts engagement because apart from the moving pictures and animations, it is normally delivered by a good communicator that draws the audience. Thus, it is preferred by many adults when learning something new.
On-the- job training	Such training delivery is suitable when the trainee is directly involved with the subject being taught.
Personal experience / Case Studies	Rather than focusing on standard theory, the training is provided by explaining real life examples and case studies.
Group discussions + Tutorials	Through group discussions, learners can share experiences and learn from each other.

3.2 Results

In this section, the results of the questionnaire are illustrated. These results supported the outline of the guidelines such that the curriculum covers the needs of the trainers and the learners.

Question 1

The criteria for the guidelines were rated as shown in Figure 1. The partners agreed that the most important criteria are *Course content*, followed by *Clarity and Relevance*. *Course learning style* and *Course language* obtained the same rank. The Learning Environment was considered the least important.

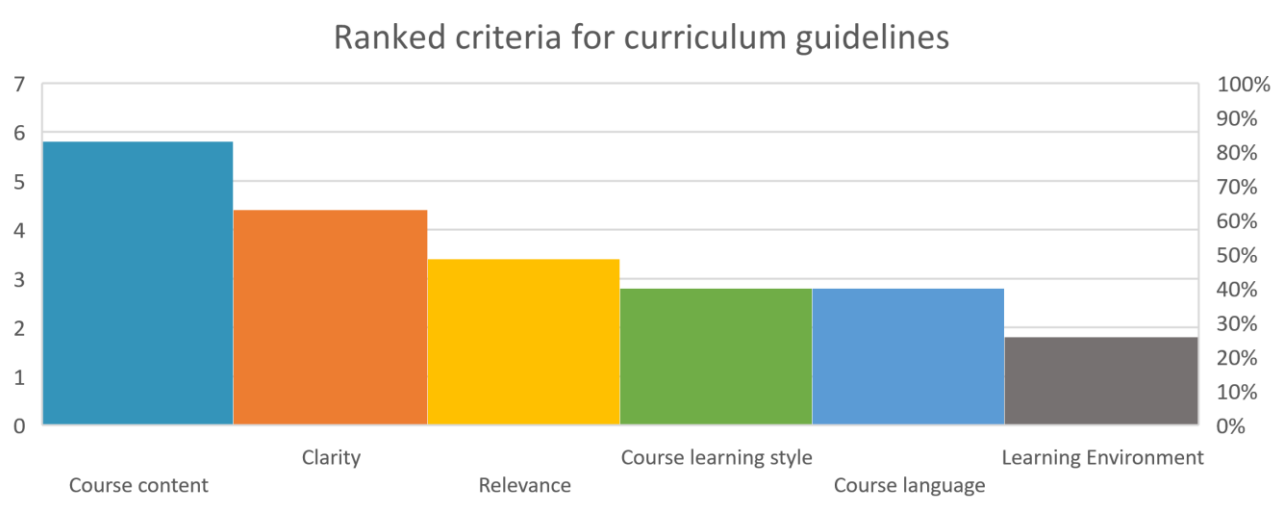

Figure 1: Ranked criteria for curriculum guidelines

Question 2

As illustrated in Figure 2, all partners agreed that the training material for trainers and learners shall be different.

Question 3

Depending on the level of experience, the partners rated the importance of topics for beginners, intermediates and advanced trainers/learners as shown in Figure 3, Figure 4 and Figure 5 respectively.

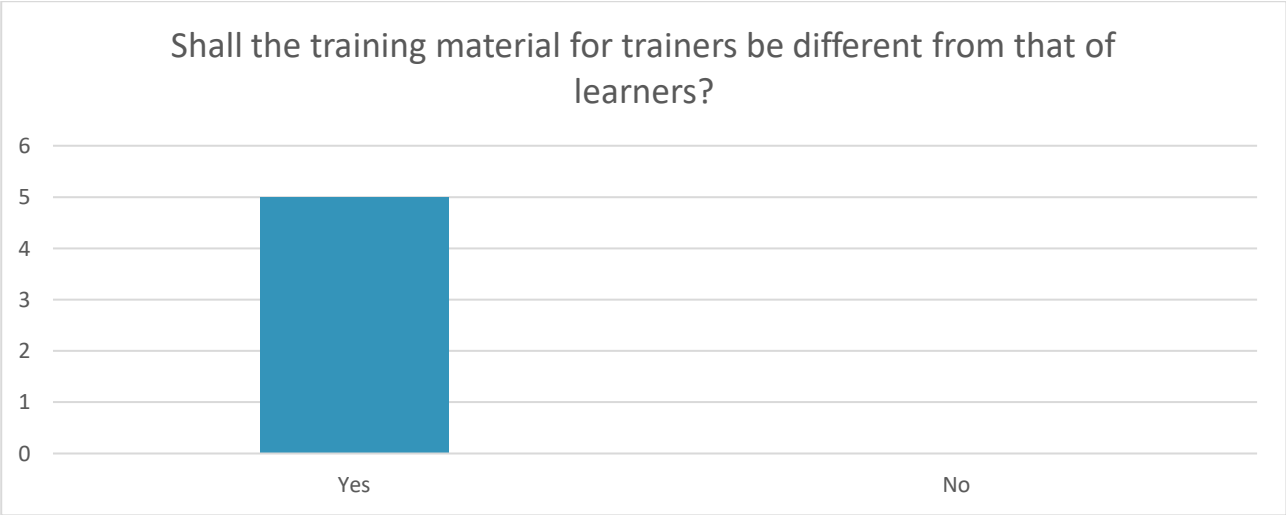

Figure 2: Difference in the training material for trainers and learners

For beginner trainers/learner, the following is the order of 3D-P topics that must be learned: 1) *General 3D-P theory*, *3D Printing*, *3D Printing Materials*, *3D Printing Resources*, *3D Printing Processes*, *3D Modelling*, *Case Studies*, and *Purchasing a printer*.

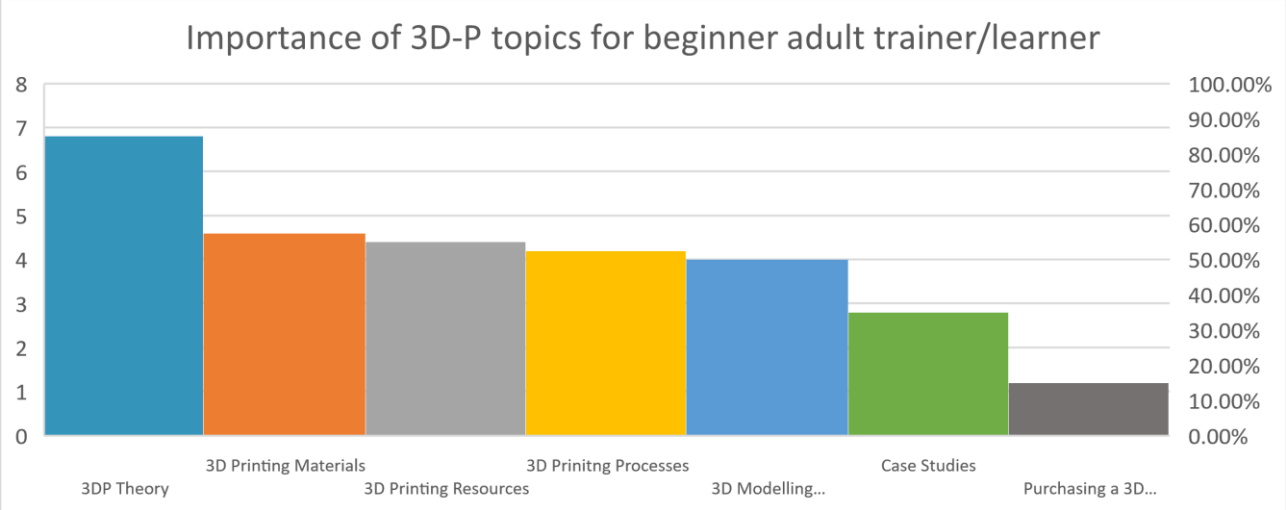

Figure 3: The importance of 3D-P topics for beginners

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For intermediate trainers/learners, the following is the order of 3D-P topics that must be learned: *3D Modelling*, *3D Printing Materials*, *3D Printing Processes*, *3D Printing Resources*, *Case Studies*, *Purchasing a printer* and *General 3D-P theory*.

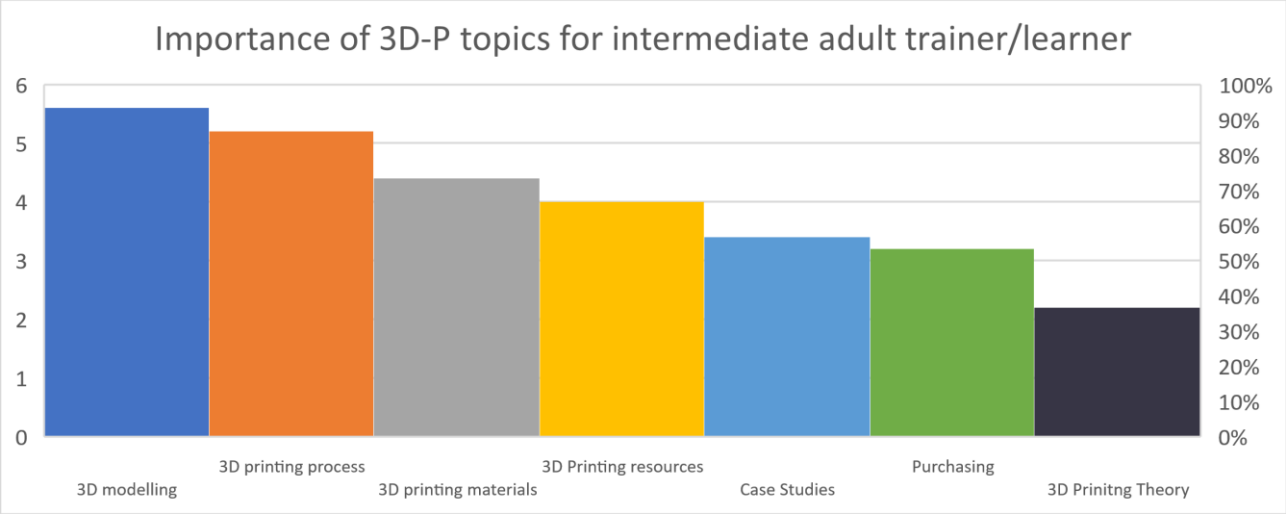

Figure 4: The importance of 3D-P topics for intermediates

For advanced trainers/learners, the following is the order of 3D-P topics that must be learned: *3D Modelling*, *Case Studies*, *3D printing Processes*, *3D Printing Materials*, *Purchasing a 3D Printer*, *3D printing Resources* and *General 3D-P theory*.

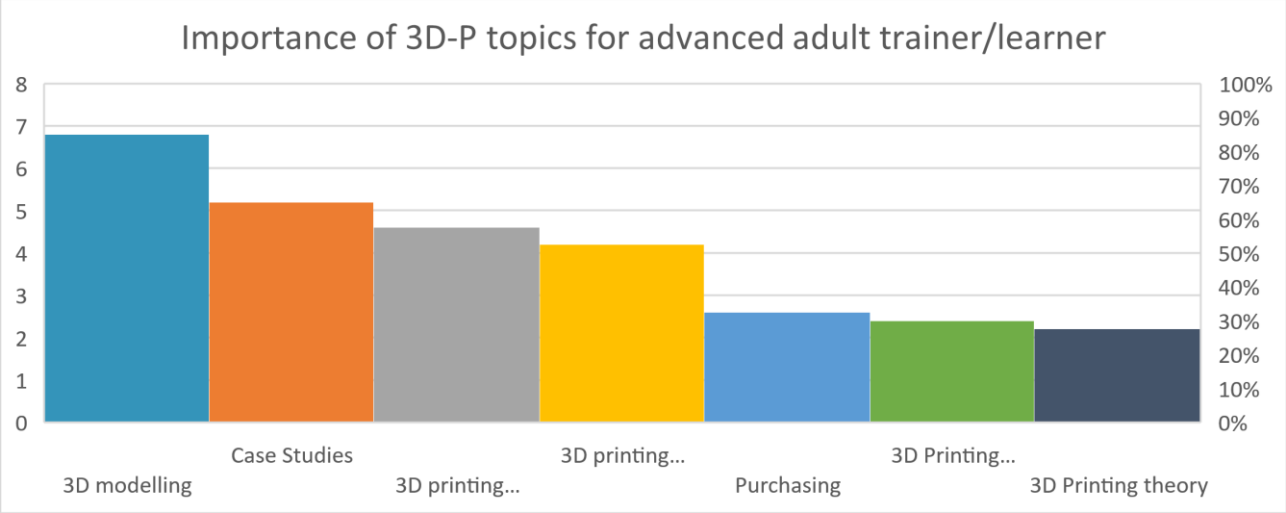

Figure 5: The importance of 3D-P topics for advanced trainers/learners

Question 4

Depending on the level of experience, the partners ranked the method of course content delivery for beginners, intermediate and advanced trainers/learners as shown in Figure 6, Figure 7 and Figure 8.

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For beginner trainers/learner (see Figure 6), the preferred order for delivering the course content is: *Reading step-by-step instructions*, *watching a 'how-to' video*, *one-to-one mentoring*, *listen to a lecture*, *on-the-job-training*, group discussion + tutorials and *Personal experience/case Studies*.

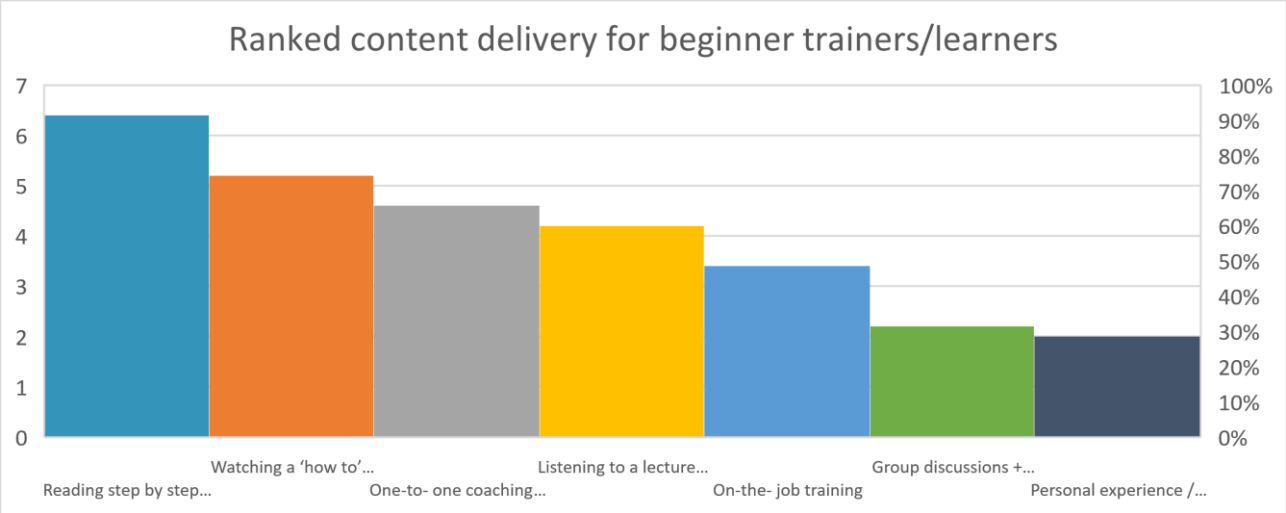

Figure 6: Content delivery for beginners

For intermediate trainers/learner (see Figure 7), the preferred order for delivering the course content is: *On-the-job training*, *watching a 'how-to' video*, *one-to-one mentoring*, group discussion + tutorials, *personal experience/case studies*, read step-by-steps instructions and *listening to a lecture*.

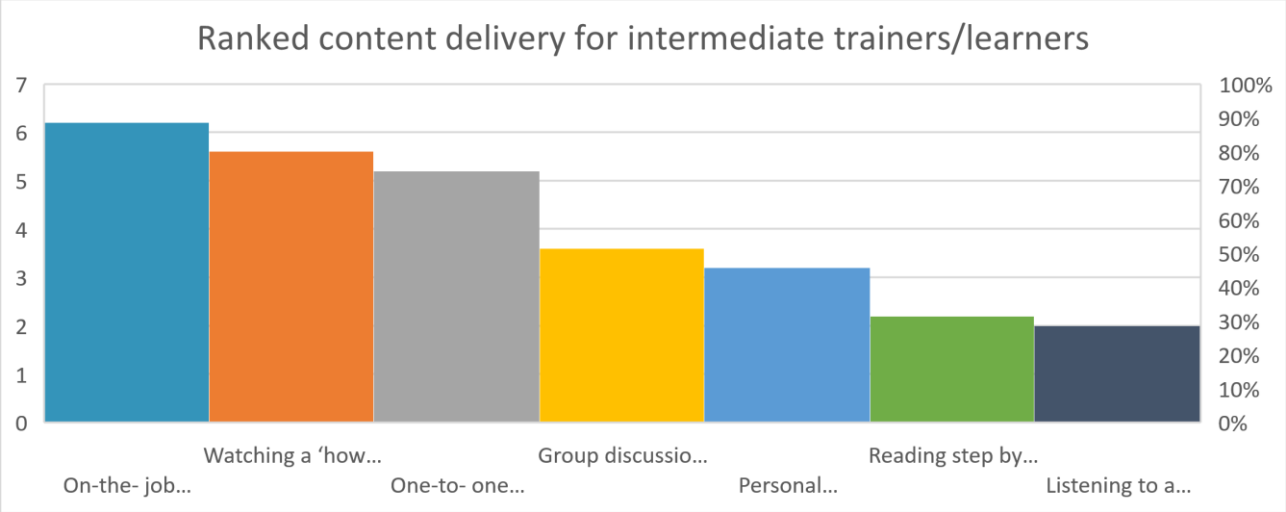

Figure 7: Content delivery for intermediates

For advanced trainers/learner (see Figure 8), the preferred order for delivering the course content is: *On-the-job training*, *personal experience/case studies*, *one-to-one mentoring*, *watching a 'how-to' video*,

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group discussion + tutorials, read step-by-steps instructions and *listening to a lecture*.

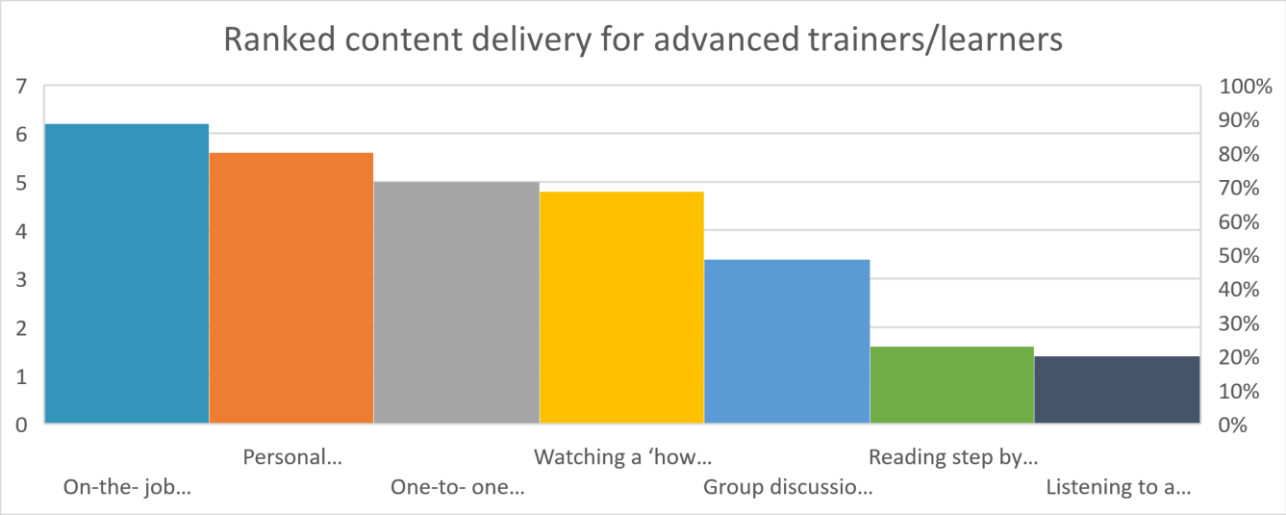

Figure 8: Content delivery for advanceds

Based on these results, the guidelines were created.

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4.0 Guidelines on the use of 3D Printing for AE

This chapter provides the foundation for building the curricula on 3D Printing for AE. Based on the preliminary study, these guidelines have been developed in such a way that allows adults to learn at stages appropriate to them. In the first sub-section, a number of terms used throughout these guidelines are defined.

4.1 Glossary of core terms in 3D Printing

Term	Definition
3D CAD model	A digital file used by Computer-Aided Design software package in which three-dimensional (3D) virtual models are created.
3D CAD model orientation	When manipulating a 3D CAD model in the software package, the 3D CAD model can be turned to any orientation. This facilitates modelling especially when certain parts of the model are obstructed when viewing from a certain angle.
3D model	A 3D model, or 3D object, refers to the physical 3D printed object.
3D model orientation	Just before printing the 3D model, the user can set (in the 3D printer software) the orientation in which the model will be printed. The orientation of the model affects the quality and certain properties of the printed 3D model. Also, the orientation of the model will affect the amount of supporting material used while printing the model.
3D printer	A 3D printer is the equipment used for printing 3D CAD models. Depending on the additive manufacturing technology used by the printer, 3D printers are classified into 3 main groups: desktop, home and industrial 3D printers. A desktop printer is used for small and basic jobs while an industrial 3D printer can print large models with special requirements.
3D Printing	Just like the process of a desktop paper printer prints ink unto paper, a 3D printer prints physical 3D objects layer by layer. The printing process is called 3D Printing.
3D Printing Technology	The 3D printing technology mainly depends on the material that needs to be printed. There exist:

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	1. Filament printers which make use of Fused Deposition Modelling (FDM) technology 2. Selective Laser Sintering (SLS) printers which is a powder-based technology 3. Stereolithography (SL) uses resin-based technology. 4. Lost-Wax 3D Printing and Casting is a combination of traditional metal casting and modern 3D printing technology. 5. Other advanced technologies involve the printing of food-based items and organism-based printing.
3D-P Beginner user	A trainer or learner who has little or no knowledge about 3D printing but does not know anything about 3D modelling.
3D-P Intermediate user	A trainer or learner who knows about the uses of a 3D printer, but his knowledge is limited. Furthermore, an intermediate user needs to use 3D printing.
3D-P Advanced user	A trainer or learner that is knowledgeable about the technology and has experience with 3D modelling. Such user frequently makes use of 3D printing to provide solutions (which can be sold), including functional parts.
3D Scanner	A scanner that scans real-world artefacts and transfers the captured image data into a 3D modelling.
Accuracy of printing	See Layer Resolution.
Additive Manufacturing	The process by which 3D CAD models are converted into physical 3D models, build up in layer by depositing material. In subtractive manufacturing, such as CNC milling and drilling, models are created by cutting away material from a solid block of the material.
Build envelope	The build envelope is the largest size (LxWxH) of a 3D CAD model which can be printed by the 3D printer.
Curve Modelling	An approach by which 3D CAD models are created by drawing curves and splines in a 3D space. By joining points and curves together, the surface of the 3D object is defined.
EBM	Similar to SLS but instead of a laser beam, an electron beam is emitted to fuse together powdered material. Refer to SLS for details of the process.

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FDM	An FDM printer uses a long plastic filament of material that comes in reels. The filament is fed to a heated nozzle where the material liquifies and applied on a platform where it immediately hardens. The nozzle moves in the X and Y directions depending on the model's G-code. When a layer is drawn, the platform lowers itself for the next layer. Typical printing material is ABS
G-code	After the 3D CAD model has been sliced into layers, the G-code file is generated which consists of a set of coordinates that dictate where the head of the printer will travel.
Layer resolution	The layer resolution, a.k.a. the layer thickness, is the thickness of each layer that is 3D printed. Depending on the brand of 3D printer, layer resolution can reach a 20-micron layer height.
Line Modelling	Line modelling is an approach by which 3D CAD models are created by drawing lines in a 3D space. By joining points and lines together, the surface of the 3D object is defined.
Lost Wax Printing and Casting	A 3D-P process used for printing special metals such as gold, silver and brass. With this process, a 3D printed wax model of the object that needs to be 3D printed is required. Wax sprues are attached to the main wax model and then covered in plaster and left to dry to create a mould. The mould is placed in an oven for several hours so that the wax is burned off and the passages and cavities from which molten metal will flow are created. Molten metal is poured into the mould and when it cools, the plaster mould is broken. The sprues are removed to get the desired object. Subsequent post-processing such as sanding, and polishing would be needed to get rid of edges and get the desired finish.
Polygon Modelling	An approach for modelling 3D CAD models using a mesh model that contains vertices, edges and faces. By changing the position of the vertices, the shape of the 3D model is modified.
Positioning precision	The accuracy by which the printer's head moves in the X and Y directions during printing. Normally, printer moves in small steps which appear to be continues movements.

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Printing Material	The printing material is the material used by the printer to create the physical object.
Printing Speed	The speed at which the printer prints the 3D model. It is measured in mm/s and the higher it is, the lower the quality of the printed object.
Printing Process	Refer to Printing Technology.
Post-Processing	Following 3D printing, the objects needs to go through a series of activities to get the desired result, depending on the printing technology used. In Stereolithography, after removing the object from the printer, excess polymer needs to be removed by inserted the model into alcohol. Then it must be exposed to UV for several hours for the material to cure. Then, the supporting material needs to be detached. Finally, sanding removes the tips of the supporting material that remained attached with the model.
Sculpting Modelling	Sculpting modelling, a.k.a. digital sculpting, is a 3S modelling approach that allows the creation of organic designs such as people, animals and complex parts.
Slicing	Slicing is the process by which a 3D model saved in STL file format is converted into a printable file. The 3D model is divided into thin slices so that the 3D printer can print the model layer by layer.
SLS	In Selective Laser Sintering, the inside of the printer is heated to a temperature that is just below the melting point of the powder being used as the material. A fine layer of powder is first spread on a platform. Then a laser beam which is guided by the G-code heats up the required areas to a temperature just above the melting point, causing the powder that was shown laser to be sintered/fused together. The platform lowers down for the next layer. Typical powder materials are Polyamide, Aluminium, Titanium, Rubber-like material and wood.
Solid modelling	Combines different geometrical shapes together to create the 3D models. Suitable when creating non-organic objects (that have a geometrical shape e.g. mechanical engineering parts, sun-glasses, etc.).
Stereolithography	Such 3D printer has of liquid polymer over a platform in a tank. Based on the G-code, a head that emits UV

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	laser beams hardens the required areas. When one layer is ready the platform lowered down in the tank This printing technology allows for the biggest parts to be created.
STL	A file format which is used by several 3D printers. This file format describes the surface geometry of a 3D model in many adjacent triangles, excluding other model parameters such as colour and texture. The 3D CAD model is normally exported (saved) as STL so that it can be used by the 3D printer software.
STL file repair	A software tool that is typically found in the software of the 3D printer. During the conversion of complex 3D CAD models into STL, some errors might be generated, resulting in missing triangles. Such errors need to be repaired before printing.
STL file resolution	The STL file resolution determines the size of the triangles that make up the 3D model.
STL file viewer	A software program that allows the user to view the 3D model saved in STL format. Typical free STL viewers are: MiniMagics[4], STL View[5] and Meshmixer[6].
Support structures	Since the 3D printed material (that belongs to the 3D CAD model)

4.2 Guidelines for Adult Trainers

Guideline #	Guideline description
1 Training a Beginner Adult Learner G_3DP_AT_1	**IF** you are an adult 3D-P trainer **AND** you need to teach beginner adult learners, **THEN** - Teach the basics about the 3D Printing process and how 3D printing differs from other manufacturing processes: Subtractive vs. Additive manufacturing. - Teach about the most important/utilised 3D-P processes and the most important specifications of the conventional desktop 3D printer. - Detail the most important/utilised 3D-P materials.

[4] http://www.materialise.com/en/software
[5] http://www.freestlview.com/
[6] http://www.meshmixer.com/

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- Show from where free resources (e.g., 3D models) can be obtained, (e.g., Thingiverse[7], Cults[8], Grabcad[9], Pinshape[10], MyMiniFactory[11]) and download STL files.
- Briefly, mention the different 3D modelling software available which can be used to create 3D models from scratch.
- (You can also download 3D Cad Models to show the basics of 3D modelling and the environment/X-Y-Z coordinate system in which objects can be modelled).
- Recommend any 3D-Prinitng services in the vicinity or online facilities which can deliver your 3D printed model by post.
- Provide a real-life example for 3D-P.

RECOMMENDATIONS

- Create step-by-step instructions for beginner learners to follow. Include a lot of diagrams/pictures.
- Show 'How-to' videos about 3D printing.
- If the student needs further explanation provide a mentoring session on a one-to-one basis.
- Download ready-made STL or 3D CAD models.
- (If you want to show a 3D modelling software, use basic software such as TinkerCAD[12], FreeCAD[13] and Sketchup[14] and use objects which have simple geometry).
- Provide an example of 3D-P for the learners' background.
- If you want to print any downloaded 3D model, consult with a competent person about the cost involved, best material, printing quality, 3D-P process and parameters used.
- Use Formative Assessment (observations, questioning, discussions, presentations, learning logs, peer/self-assessments) to check for understanding during the learning process. Through the feedback gained by formative assessment adjust the teaching and course content delivery methods to accommodate the needs of the students in future instructions.

[7] https://www.thingiverse.com/
[8] https://cults3d.com/en
[9] https://grabcad.com/
[10] https://pinshape.com/
[11] https://www.myminifactory.com/
[12] https://www.tinkercad.com/
[13] https://www.freecadweb.org/
[14] https://www.sketchup.com/

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	- A summative assesment (e.g. a test, quizz or assignment) could be used to evaluate the students knowledge at the end of the course and thus giving a grade or compare it to some benchmark.
2 Training an Intermediate Adult Learner G_3DP_AT_2	**IF** you are an adult 3D-P trainer **AND** you need to teach an intermediate adult learner, **THEN** - Ensure that the adult learners know the basic 3D printing process steps. Then focus on each aspect of 3D printing in detail, starting with 3D modelling. - In detail, explain the 3D space and X-Y-Z coordinate system in which objects can be modelled. - Mention different 3D modelling software available which can be used to create 3D models from scratch. - Show how simple to medium-complex 3D models are created with a preferred 3D modelling software* (see recommendation). - Briefly, show from where free resources (e.g., 3D models) can be obtained. - Explain how the 3D model is converted into small triangles when the file is converted to STL. - Explain how the 3D printer software threats the STL file before the model is uploaded into the printer. - Explain the difference between the build and support material which are both contained in the build envelope of the 3D Printer. - Guide learners on how to best position the 3D model for printing to achieve the best properties, followed by some printing parameters (incl. temperature, layer thickness, printing speed and different materials) which can be changed to modify the printing accuracy, printing time, amount of support material, surface finish, etc. - Apart from the conventional desktop 3D Printer, teach about other additive manufacturing processes (e.g. Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Stereolithography and Lost Wax Printing and Casting) that are used in various industries and for specific applications. Provide a list of benefits and drawbacks for each process such that the adult learners can select the appropriate printing technology for a particular application.

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- Along with printing processes, provide details of the materials that can be used. Make sure to consult with catalogues of different brands because 3D printing is still an evolving technology. For instance, not all desktop 3D Printers can print with wood material.
- Provide real-life applications for 3D-P by showing case studies.
- Recommend any 3D-Prinitng services in the vicinity or online facilities which can deliver your 3D printed model by post.
- Should the students be interested to purchase a 3D printer for their home, go through the important specifications of a 3D printer and highlight what makes an appropriate printer for their needs.

RECOMMENDATIONS

- Make sure that you have access to a 3D printer (and be able to 3D print) when explaining any of the curriculum for intermediate learners.
- *Make sure that you are a skilful user in one of the 3D modelling software. Depending on the software chosen (Inventor[15], Maya[16], SolidWorks[17], CATIA[18], Rhino 3D[19], Blender[20], SCAD[21], Sculptris[22], 3D Studio[23], Fusion360[24]), models can be created by adding simple geometry or through sculpting. Show examples of how to create blocks, holes, round edges and other medium-complex models.
- Always show videos when explaining theory which cannot be shown live.
- Use case-studies to explain different applications or visit local organisations to see how 3D printing is utilised on a daily basis.
- Use Formative Assessment (observations, questioning, discussions, presentations, learning logs, peer/self-assessments) to check for understanding during the learning process. Through the feedback gained by formative assessment adjust the teaching and course content

[15] https://www.autodesk.eu/products/inventor/overview
[16] https://www.autodesk.eu/products/maya/overview
[17] http://www.solidworks.com/
[18] https://www.3ds.com/products-services/catia/
[19] https://www.rhino3d.co.uk/
[20] https://www.blender.org/
[21] http://www.openscad.org/
[22] http://pixologic.com/sculptris/
[23] https://www.autodesk.eu/products/3ds-max/overview
[24] https://www.autodesk.com/products/fusion-360/overview

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		delivery methods to accommodate the needs of the students in future instructions. - A summative assesment (e.g. a test, quizz or assignment) could be used to evaluate the students knowledge at the end of the course and thus giving a grade or compare it to some benchmark.
3 Training an Advanced Adult Learner G_3DP_AT_3	**IF** you are an adult 3D-P trainer **AND** you need to teach an advanced adult learner, **THEN**	- Ensure that the adult learners know the basic 3D printing process steps. Then focus on each aspect of 3D printing in detail, starting with 3D modelling. - In detail, explain the 3D space and X-Y-Z coordinate system in which objects can be modelled. - Mention different 3D modelling software available which can be used to create 3D models from scratch. - Show how complex 3D models are created with a preferred 3D modelling software*. - Explain the difference between solid modelling and surface modelling. - Show in detail how advanced modelling tools can be used to create complex shapes. - Briefly, show from where free resources (e.g., 3D models) can be obtained. - Show and explain how 3D scanners can be used to capture a digital 3D model of a real-life physical object. Explain the two techniques Photogrammetry and Light-based scanning) used in 3D scanning. Show how a 3D model can be repaired through software. - Go over some typical errors encountered when modelling and provide solutions. - Explain how the 3D model is converted into small triangles when the file is converted to STL and how resolution of the STL file can be increased or decreased within a CAD package. - Provide important considerations when printing different parts that need to be assembled together. - Explain how the 3D printer software threats the STL file before the model is uploaded into the printer. - Explain the difference between the build and support material which are both contained in the build envelope of the 3D Printer.

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- Guide learners on how to best position the 3D model for printing to achieve the best properties, followed by some printing parameters (incl. temperature, layer thickness, printing speed and different materials) which can be changed to modify the printing accuracy, printing time, amount of support material, surface finish, etc.
- Highlight sources of inaccuracies along the different phases of the 3D printing process and how such errors can be mitigated
- Provide several real-life applications for 3D-P by showing case studies.
- Apart from the conventional desktop 3D Printer, teach about other additive manufacturing processes (e.g. Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Stereolithography and Lost Wax Printing and Casting) that are used in various industries and for specific applications. Provide a list of benefits and drawbacks for each process such that the adult learners can select the appropriate printing technology for a particular application.
- Explain what to look for when purchasing a 3D printer for their home by going through the important specifications of a 3D printer and highlight what makes an appropriate printer for their needs.
- Along with printing processes, provide details of the materials that can be used. Make sure to consult with catalogues of different brands because 3D printing is still an evolving technology. For instance, not all desktop 3D Printers can print with wood material.
- Recommend any 3D-Prinitng services in the vicinity or online facilities which can deliver your 3D printed model by post.

RECOMMENDATIONS

- Make sure that you have access to a 3D printer (and be able to 3D print) when explaining any of the curriculum for advanced learners.
- *Make sure that you are a skilful user in one of the 3D modelling software. Depending on the software chosen (Inventor, Maya, SolidWorks, CATIA, Rhino 3D, Blender, SCAD, Sculptris, 3D Studio, Fusion360), models can be created by adding simple geometry or through sculpting. Show examples of how to create blocks, holes, round edges and other medium-complex models.

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- Always show videos when explaining theory which cannot be shown live.
- Use case studies to explain different applications or visit local organisations to see how 3D printing is utilised on a daily basis.
- Encourage learners to discuss problems encountered during 3D printing and how they solved a problem.
- Provide problems to be solved in groups
- Use Formative Assessment (observations, questioning, discussions, presentations, learning logs, peer/self-assessments) to check for understanding during the learning process. Through the feedback gained by formative assessment adjust the teaching and course content delivery methods to accommodate the needs of the students in future instructions.
- A summative assesment (e.g. a test, quizz or assignment) could be used to evaluate the students knowledge at the end of the course and thus giving a grade or compare it to some benchmark.

4.3 Guidelines for Adult Learners

Guideline #	**Guideline description**
1 Beginner Adult Learner G_3DP_AL_1	**IF** you are a beginner 3D-P adult learner **AND** you need to quickly learn about 3D-P **THEN**, - Read a beginner's guide to 3D printing and the basic theory concerning the subject, including: the basic 3D printing process for a desktop 3D printer (e.g. FDM and SLS), basic nomenclature of 3D-P and the materials that can be printed. If you are up to the challenge and are interested, learn about the other different 3D-P processes (e.g. Powder laser sintering, Stereolithography and Lost Wax and Casting). - Understand the file formats used for 3D modelling and 3D printing. - Know from where to download readily available (royalty free) 3D CAD models (in STL format) from online resources such as Thingiverse, Grabcad and Myminifactory. - See (and touch) different 3D printed objects by visiting a printer manufacturer website or read a catalogue and see how people's ideas are brought to life.

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- Learn about 3D-P facilities near you that can print your models or support you with any queries on printing your own models.

RECOMMENDATIONS

- Read step-by-steps instructions and watch videos to learn more about the subject.
- Consult with a technical people to give you live demonstrations.
- Read and ask questions in forums to improve your knowledge on the subject.
- Revisit what has been learned and do further research (e.g. read an article/case study or watch a video) to expand your knowledge on the subject
- Do a self-assessment to monitor your progress.

2
Beginner
Adult Learner

G_3DP_AL_2

IF you are a beginner 3D-P adult learner **AND** you need to quickly start printing 3D CAD models **THEN**

- Understand the file formats used for 3D modelling and 3D printing.
- Know from where to download readily available (royalty free) 3D CAD models (in STL format) from online resources such as Thingiverse, Grabcad and Myminifactory.
  Download the STL file.
- Learn about and how to use 3D scanners to acquire 3D CAD models from physical objects.
- Learn about 3D-P facilities near you that can print your models or support you with any queries on printing your own models.
- Consult with an 3D-P expert about printing process and material for the downloaded model. Poly Lactic Acid (PLA) filament or Acrylonitrile Butadiene Styrene (ABS) filament are one of the most common materials used for 3D-P because of their properties.

RECOMMENDATIONS

- See (and touch) different 3D printed objects by visiting a printer manufacturer website or read a catalogue and see how people's ideas are brought to life.
- Use objects which have simple geometry to reduce complexity and costs.
- Read step-by-steps instructions and watch videos to learn more about the subject.

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- Consult with a 3D-P expert on the best printing orientation of the model, cost of printing and printing time.
- Use PLA for most jobs but if you require less brittle parts or can withstand higher temperature use ABS.

3 Beginner /Intermediate Adult Learner G_3DP_AL_3	**IF** you are a beginner/intermediate 3D-P adult learner **AND** you need to quickly start modelling your own basic 3D models **OR** alter design of a downloaded model **THEN** - Refer to the relevant steps suggested in Guidelines 1 and 2 for beginner adult learners. - Learn about different 3D CAD modelling approaches (solid modelling, digital sculpting, Polygon modelling, line and curve modelling) and choose your preferred style of modelling. - Choose a software package that utilises the selected 3D modelling approach. Learn how to use the software to create basic shapes, open and repair files, and add/subtract material to downloaded models. You can download a free 3D modelling software package on your computer such as TinkerCAD or work online by 3D modelling on your internet browser (3DTin[25]). Free and online software packages provide you the basic tools for creating and viewing 3D models. For more complex modelling requirements, high-end software needs to be purchased, e.g. Autodesk's Fusion360. Normally, you can download a trial before purchasing the full version. - Explore and practice to become acquainted with the interface and tools of the software. Create your own (basic) model or modify an existing one. - Use constraints when modelling. - Learn how to generate STL files from 3D CAD models. - Find a 3D-printing facility near you and consult with an expert if you have doubts. - Print your model. **RECOMMENDATIONS** - Watch videos and online tutorials to learn more about 3D modelling. Always practise what you have learned. - Consult with a 3D modelling and 3D-P experts. Note that 3D model orientation in the 3D printer will affect the quality of the printed model.

[25] https://3dtin.wordpress.com/

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- Use 3D scanners to 3D model existing physical artefacts. Make sure that the exported file is free from errors or that the model is repaired prior printing.
- Scale down your model if the object to be printed is larger than the printing envelope.

4 Intermediate Adult Learner G_3DP_AL_4	**IF** you are an intermediate 3D-P adult learner **AND** you need to create large or complex 3D models that require multiple parts to be assembled **THEN** - Refer to the relevant instructions in Guidelines 3 for Beginner/Intermediate Adult Learner. - Get informed about different 3D printers and select the right one for your purposes. If you plan to use 3D printing many times, it is not a bad idea to purchase your own 3D printer rather than using 3D printing suppliers. - Ensure that your design is reasonably sound o Check whether your design can be created with a 3D printer that prints multiple colours, thus avoid splitting the design in multiple sub-components and assembly requirements. o Read and understand the datasheet of the printing material to understand the properties that your model will have once the material has cured. o Consider adding dimensional tolerances (suitable clearance between mating parts) o Decide on the printing resolution (layer thickness) and ensure that the STL file is free from errors. o Design assembly features. The software package should have modelling tools that facilitate the design of such features (E.g. Autodesk Inventor has a toolbox called Plastic which guides engineers designing bosses, lips, snap fits and fillets) - After modelling each individual digital 3D part, create an assembly project and put together each individual digital 3D part just like the parts will be assembled in real life. Make use of constraints to bring parts together. **RECOMMENDATIONS** - Depending on the mechanism that you want to create, ensure that you have relevant (engineering) knowledge.

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- Watch videos and online tutorials to learn about 3D modelling.
- Consult with a 3D modelling and 3D-P experts.
- Ensure that the supporting material of a part is not residing on surfaces that are critical to the functional characteristics.
- Although it is a good idea to orient your model such that the number of supporting material is decrease, make sure that the support material does not reside on critical surfaces.
- Select a suitable printing material, process and printer for the job.

5 Advanced Adult Learner

G_3DP_AL_5

IF you are an intermediate 3D-P adult learner **AND** you need to create functional 3D models **THEN**

- Refer to the relevant instructions in Guidelines 4 for Intermediate Adult Learner.
- Learn how to do a dynamic simulation in an assembly project to ensure that all the components and their respective location would not interfere with desired function.
- Consider in learning different modelling approaches in achieving the desired result so that if one solution does not work, an alternative method can be used.

RECOMMENDATIONS

- Look at case studies to learn how different people used 3D printing to cater for their needs.
- Always consult with experts and datasheets when designing parts for 3D-P
- If your model is composed of large solid amounts of plastic, consider in creating a shell model to reduce the amount of plastic used. Consider of having a wall thickness of at least 2mm.
- Learn a second 3D modelling software package that has a different modelling approach (e.g. line modelling vs. solid modelling).

4.4 Guidelines for AE stakeholders

1 Stakeholder (any level)

G_3DP_S_1

IF you are a type of stakeholder **AND** you need to understand the importance of 3D-P in today's world **THEN**

- Learn how 3D-P is shaping our world by reading about or watching videos on how 3D-P is changing the way artefacts are manufactured and its uses in everyday life. Check case studies in specific

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areas relevant to your field or multiple different fields.
- Read a beginner's guide to 3D printing and the basic theory concerning the subject, including: the basic 3D printing process for a desktop 3D printer (e.g. FDM and SLS), basic nomenclature of 3D-P and the materials that can be printed.

RECOMMENDATIONS

- Experience the process of 3D printing from start to end by visiting a 3D printing facility.

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5.0 Critical Implementation Actions

To achieve the overall aim of the project and create an original training course, the consortium needs to work on the following tasks:

- explore several different case studies in which 3D-printng is used in AE;
- develop a Curriculum targeted at engaging adults to learn 3D Printing;
- develop an innovative e-learning content to support adult learners acquire expertise on the use of 3D printing;
- disseminate & exploit the results of the 3D-Help project and ensure that the courseware developed is openly available to at least 1000 other Adult Trainers across Europe.

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6.0 Introduction to the Case Studies

Although initially 3D printers were created to be used for industrial designers, mechanical engineers, package designers and graphic artists in order to rapid prototype and understand a product's aesthetic and functional appeal, nowadays the use of 3D printing is very vast and has spread in several industries. This is mainly because the technology has become cheaper and easier to use.

This means that the audience to which 3D printing has become relevant has widened over the years. Thus, it is important to consider areas that are not just related to science subjects but also sectors that have elements of art and management.

The partners have decided to focus on 5 topics: Culture, Entrepreneurship, STEM (Science, Technology, Engineering and Mathematics), Languages and Arts, and Social Sciences. Detailed case studies are listed in a separate document.

Figure 9: Case study area

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7.0 Conclusions

This report has provided the guidelines on which the curriculum of 3D-P for AE will be based on. The important highlights of the report can be condensed as follows:

1) Understand the various areas in which adults will typically find 3D-P useful through case studies. The case studies are necessary to provide plenty of examples.
2) Explain the different aspects of 3D-P trough rich visual content. Use photos and videos where necessary and guide trainers/learners step-by-step.
3) Discriminate between the trainer and the learner and the respective level of knowledge on 3D-P. Provide different training material accordingly.
4) Learn the nomenclature used in 3D-P.
5) Learn 3D-modelling. The more experience one gets on 3D printing, the focus moves towards 3D modelling.
6) Assess what has been learned to continuously evaluate the training material, the delivery and the individual knowledge.
7) Have access to 3D-P online resources and 3D printers to understand and practice the concepts of 3D-P.

Following the completion of the project's deliverables, it is expected to have tools that will be able to boost the development of the 3D printing skills among the adults, thus allowing them to take advantage on the 3D printing revolution. The tools will include a multilingual 3D printing course dedicated to AE, guidelines for AE trainers and students and a multilingual e-learning platform freely accessible for anyone.

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Appendix 1

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Questionnaire: Understanding the needs of adult trainers and learners in developing the guidelines on the use of 3D Printing in Adult Education.

1. Please rank the following aspects of a curriculum guidelines for adult trainers and learners alike based on their importance.

Criteria	Rank	*Example*
Course content		*1*
Course learning style		*5*
Clarity		*2*
Course language		*6*
Learning Environment		*4*
Relevance		*3*

2. Shall the training material for adult trainers be different from that of adult learners?

Yes ☐
No ☐

3. Please rank the importance of information to be thought based on the level of knowledge/experience of the trainer/learner.

Training material	Beginner	Intermediate	Advanced	*Example*
3D Printing theory				*1*
3D Printing Materials				*5*
3D Printing Processes				*2*
3D Printing Resources				*7*
3D Modelling				*6*
Case Studies				*4*
Purchasing a 3D Printer				*3*

4. Please rank the most effective way of delivering the training to adult trainers and adult learners.

Content delivery	Beg.	Inter.	Adv.
Reading step by step instructions			
Listening to a lecture/presentation			
One-to-one coaching/mentoring			
Watching a 'how to' video			
On-the-job training			
Personal experience / Case Studies			
Group discussions + Tutorials			

5. Please list additional comments that you think are important for the guidelines.

_____

_____

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