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Reshaping teaching and learning with 3D printing technologies

Michael A. Kolitsky

The NMC (New Media Consortium) Horizon Report in 2014 listed 3D printing as a technology that is two to three years from widespread adoption. In this report, 3D printing was also classified as a disruptive technology especially for the manufacturing sector. A review of the current literature ranging from journal publications to news reports of how 3D printing technologies are changing the way teachers teach and students learn is the focus of this report. 3D printing technologies include 3D printers, 3D scanners and the recently introduced 3Doodler pen. The widespread rise in popularity of 3D printing technologies is directly correlated with their availability at a lower cost in the consumer market. 3D printing technologies are causing educators to refocus attention from the digital or virtual environment to the real world, where 3D printed objects can be touched and felt. The stl (stereolithography) file is the common file type used for 3D printing and although CAD (computer-aided design) software is the ideal software for making stl files, there are other software choices for producing CAD-free stl files like PhotoToMesh and 123D Catch. How 3D printing technologies are currently being used across the curriculum by teachers as well as students demonstrates the increasing interest in and success with its usage in the learning environment. The growing interest in making and using 3D printed tactile learning objects by the blind or visually impaired points to a future where image-intensive courses and textbooks will have available 3D prints when touch is the primary method for learning. 3D printing and related technologies appear poised to become even more significant as it becomes clearer from the work of early adopters how best these technologies can be employed for teaching and learning.

News reports covering what can be made using 3D printers include artificial limbs for children[1], tracheal implant for a baby[2], anatomical organs from CAT scan data[3], food in space[4], cars[5] and even guns[6]. By searching Google Trends, one can find a gradual increase in number of searches beginning around 2010 so that by 2014, a search on the words "3D printing" shows 76,100,000 results. The NMC (New Media Consortium) Horizon Report in 2014 listed 3D printing as a technology that is two to three years from widespread adoption[7]. 3D printing has also been classified as a disruptive technology especially for the manufacturing sector as the prices drop for a consumer grade 3D printer and more 3D printers appear in homes, public libraries, schools, colleges and universities. The disruption in the manufacturing sector comes from being able to make at lower cost at home or at work what one now buys or orders from a company or business. But, it is the changing awareness of what 3D printing technologies bring to the teaching and learning process that is just beginning to emerge as teachers and students explore how making things adds to the learning experience.

From the virtual to the real world

Until relatively recently, a 3D printer was a high-end tool for use primarily by engineers and architects but with the advent of 3D printers for the consumer market, students and teachers in the school, college and university sectors can now utilize the making of things as a pedagogical tool for both learning how

[1] Ch. Jackson, *Students Build Prosthetic Arm for 6-Year-Old With 3D Printer*, „Guardian Liberty Voice", 28.07.2014, http://guardianlv.com/2014/07/students-build-prosthetic-arm-for-6-year-old-with-3d-printer-video, [28.07.2014].
[2] M. Fessenden, *3-D printed windpipe gives infant breath of life*, „Nature", 28.05.2013, http://www.nature.com/news/3-d-printed-windpipe-gives-infant-breath-of-life-1.13085, [11.10.2014].
[3] 3DSystems, http://www.3dsystems.com/solutions/services/bespoke-modeling, [20.08.2014].
[4] *3D Printing: Food in Space*, NASA, http://www.nasa.gov/directorates/spacetech/home/feature_3d_food_prt.htm, [26.06.2014].
[5] T. Kermeliotis, *Futuristic drive: Step inside a 3D printed car*, CNN, 26.06.2014, http://www.cnn.com/2014/06/26/tech/futurisitc-drive-step-inside-3d, [11.10.2014].
[6] J. Biggs, *Engineers Build The World's First Real 3D-Printed Gun*, TechCrunch, 07.11.2013, http://techcrunch.com/2013/11/07/3d-printed-gun, [20.08.2014].
[7] *Horizon Report*, *2014 Higher Education Edition*, http://cdn.nmc.org/media/2014-nmc-horizon-report-he-EN-SC.pdf, [28.05.2014].

to use this technology as well as using the objects made by 3D printers for learning in many disciplines. One can sense a pedagogical shift away from always thinking about things in the virtual world to working with and designing things for the real world that can be touched supporting a way of learning not possible when objects only exist in the virtual world. The real world existence of an object that can be sensed by touch opens new avenues of learning for all students but especially for those who are blind or visually impaired. One might compare this time in the introduction of 3D printers to the early 1980's when desktop computers were first being made available and affordable to the consumer market. Think of all the new opportunities for learning and teaching that have emerged from those days to the present and ask if that is also what we can expect for the impact of 3D printing in our future.

Pedagogy underpinning 3D printing technologies

A report of a collaboration between the University of Virginia School of Engineering and Applied Science and the Curry School of Education stated that 3D printing is transforming learning in their undergraduate mechanical engineering courses by employing 3D printers as a pedagogical tool that increases active student engagement, emphasizes collaborative learning, increases student exposure to problem solving skills and content knowledge, increases 3D visualization skills and emphasizes learning through the iterative design process[8]. 3D printers fit exceptionally well into an iterative design pedagogy as the making of a real world object from a digital model gives students the opportunity to see where redesign is needed once the object is 3D printed and then the process of redesign and 3D printing is continued until the object being printed meets its design expectations. The process of iterative design is thought to increase innovation in designs since at each redesign step the solution provides an opportunity for new thinking about how to solve the design problem[9]. 3D printing has also been described as being able to transform what the student imagines into a practical setting that can help to analyze real world problems[10]. Other reports have viewed this type of pedagogy in terms of constructivist learning theories in which students become the creative and critical thinkers rather than always relying on the instructor[11]. In this way, constructivist theories coming from the education field that encourage students to search for multiple solutions to a problem mesh well with the use of the iterative design problem solving pedagogy seen in the engineering field.

3D printing technologies

There are currently three types of 3D printing technologies available for study in the form of 3D printers, 3D scanners and the 3Doodler pen. 3D printing is also described as additive manufacturing because it builds a digital object one layer at a time from the bottom to the top. Another type of 3D printing is termed CNC milling or subtractive manufacturing because it removes material one layer at a time from the top to the bottom. A CNC milling machine, however, is usually more expensive than a comparable 3D printer for the consumer market.

3D printers

MakerBot produced the first consumer 3D printer several years ago and is now a subsidiary of Stratasys. The author purchased a MakerBot Replicator 2 3D printer[12] in November, 2012 which extrudes a single stream of heated PLA (polylactic acid) plastic filament and builds an object following digital directions obtained from files in stl format. The file name of stl stands for stereolithography but you will also find stl referred to as surface tessellation file since the actual file format uses a triangular numerical code to create the surface of the structure being printed. This triangular method of defining a surface is referred to as tessellation. The Replicator 2 has a large build platform and can extrude filament at 100 Micron layer height that is useful for smooth surface production in the finished 3D print. The extrusion of filament at 100 Micron layer height provides more detail and smoothness to the printed product but it also takes a longer time to make the 3D print and two larger extrusion sizes are available for a faster build time if a slightly less smooth surface on the completed 3D printed product is acceptable.

MakerBot now offers four other 3D printer models[13] for the consumer market. The Replicator 2x has a heated build platform and two extruders so it is capable of building objects composed of two different colored plastic filaments but be aware that it is advertised for the experimental user. The Replicator Mini has a smaller build volume for making an object and extrudes a 200 Micron filament thread and the

[8] *Using 3D Printers to Transform Learning in Undergraduate Mechanical Engineering Courses*, University of Virginia – Curry School of Education, http://curry.virginia.edu/research/centers/castlhe/project/using-3d-printers-to-transform-learning-in-undergraduate-mechanical-enginee, [05.09.2014].
[9] D. White, *Why 3D Printing in Education*, http://3dprintineducation.wordpress.com/why-3d-printing-in-education, [04.02.2014].
[10] Ch. Eagen, *What is 3D Printing and What Can it do?*, 13.03.2014, http://prezi.com/wmosa6dbogzb/3d-printing, [13.03.2014].
[11] M. Kostelnik, *3D Printers*, 30.03.2014, http://prezi.com/4eszirothuzf/3d-printers, [03.30.2013].
[12] MakerBot, http://store.makerbot.com/compare, [28.05.2014].
[13] Ibidem.

Replicator Z18 is a taller model with a 100 Micron filament extruder but also has a heated chamber. Other sources also exist for purchasing consumer grade 3D printers such as the Cube and CubeX produced by 3DSystems[14], Type A Machines[15] and ROBO 3D[16]. Choice of a 3D printer hinges on what budget is available, the size of 3D print product able to be produced, the filament extrusion diameter and type of plastic filament to be used. The author prefers PLA filament since it is considered "green" being made from lactic acid polymerization and does not emit any smell when melted which fits better for home or classroom use.

MakerBot has also recently expanded their 3D printing business throughout Europe by the recent purchase of a German reseller, Hafner's Buro[17]. Hafner's Buro is described as being positioned to bring desktop 3D printing sales and services to major European countries. The new European subsidiary will be known as MakerBot Europe and will service Austria, Belgium, Croatia, the Czech Republic, Denmark, Finland, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Poland, Romania, Russia, Serbia, Spain, Sweden, Switzerland, Turkey, Ukraine, and the UK.

3D scanning

MakerBot also now has a 3D scanner[18] with MakerWare for Digitizer software for calibration and for choosing the correct lighting adjustment before scanning. Objects that fit within an 8 x 8 inch cylindrical volume can be fully scanned to produce an stl file for 3D printing and the time for object scanning is under10 minutes.

The MakerBot scanner is an example of a low cost hardware scanner but there is also a software choice for 3D scanning called 123D Catch[19] from AutoDesk which 3D scans large objects that would not fit within the MakerBot scanner space. 123D Catch is an app that works with PC's, iPhones and iPads and captures many photos around the object being scanned which are sent to the AutoDesk cloud for stitching all the captured images into an stl file that can then be downloaded to be made into a 3D printed object on a desktop 3D printer or if desired, AutoDesk will make the object for you for a fee. Another advantage of 123D Catch is that the app and use of the AutoDesk cloud is free although users are encouraged to become members for a monthly fee that provides broader support services.

3Doodler pen

Another 3D printing technology that became available in early 2014 is the 3Doodler pen[20]. The 3Doodler looks like a thick pen that can extrude plastic colored filament in a free-hand manner so that sculpting and drawing is possible. No 3D print file is produced with the 3Doodler pen. And recently, a new foot pedal device was added for greater control when using the 3Doodler very much like the foot pedal does in a sewing machine.

Source of files for 3D printing

There are two general choices for getting files for 3D printing. First, one can search repositories such as Thingiverse[21] for stl files that suit your purpose or second, one can make the files using CAD (computer-aided design) software such as Maya[22] or other commercial CAD software[23] or use a software approach that does not require CAD such as PhotoToMesh[24] or 123D Catch[25].

Ready to use 3D print files

Thingiverse has over 100,000 stl files for download and are free to use for educational projects. Stl files that others have produced are especially useful for projects that involve learning how to use a 3D printer. 3D printers are not a "plug and play" technology. There is a skill set and knowledge base that must be developed to utilize a consumer grade 3D printer. The student must be able to follow directions to be able to (a) level the build platform or plate, (b) choose the extrusion layer height and internal density of the object being printed, (c) load and unload plastic filament, (d) remove 3D printed object from a build platform and (e) follow a 3D print being printed to look for signs of edge warping. Hands-on skills technique and being able to follow step-by-step instructions are practiced in the process of learning to use a 3D printer. In addition to using already made stl files from Thingiverse for learning how to use a 3D printer, some stl files

[14] 3DSystems, http://cubify.com/en/Education/Products, [28.05.2014].
[15] TypeA Machines, http://www.typeamachines.com/, [28.05.2014].
[16] Robo 3D, http://www.robo3dprinter.com/, [28.05.2014].
[17] L. Bell, *Makerbot expands 3D printing services into Europe*, „The Inquirer", 01.08.2014, http://www.theinquirer.net/inquirer/news/2358453/makerbot-expands-3d-printing-services-into-europe, [28.05.2014].
[18] MakerBot Industries, http://store.makerbot.com/digitizer, [28.05.2014].
[19] Autodesk, http://www.123dapp.com/catch, [28.05.2014].
[20] 3Doodler, http://the3doodler.com/, [28.05.2014].
[21] Makerbot Industries, http://www.thingiverse.com/, [28.05.2014].
[22] Autodesk, http://www.autodesk.com/products/maya/overview, [28.05.2014].
[23] MakerBot Industries, http://www.makerbot.com/blog/2011/02/25/3d-design-software-101/, [28.05.2014].
[24] Ransen Software, http://www.ransen.com/phototomesh/, [28.05.2014].
[25] Autodesk, http://www.123dapp.com/catch, [28.05.2014].

from sites such as Digital Morphology[26] can be used for study in comparative anatomy courses and the new NIH stl repository named NIH 3D Print Exchange[27] is designed to provide an interactive website for the exchange of 3D printable models for STEM education. The author has seven stl files on the NIH 3D Print Exchange that can be used for making tactile learning objects for the blind or visually impaired so they can by touch and feel learn what sighted students see when using a microscope[28].

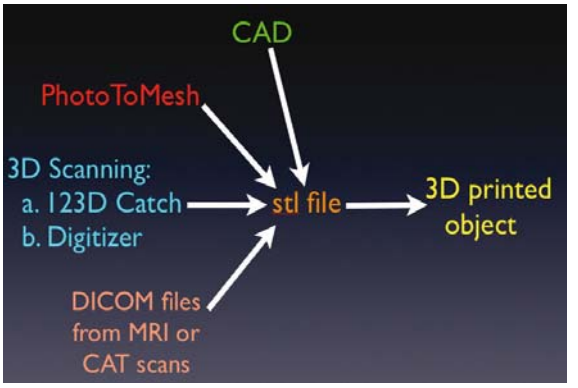
Making your own 3D print files

Students in engineering, especially mechanical engineering and also architecture are expected to master CAD programs. But, for many students as well as faculty in other disciplines, CAD software is not always one they are familiar with or wish to take the time to learn. For this reason, it is important to recognize that other options are available to produce stl files for 3D printing that do not demand a knowledge of CAD or expertise in that area. One program named PhotoToMesh[29] is especially useful in that it can make stl files from 2D photos in jpg file format. PhotoToMesh raises white or lighter colors on the Z axis and lowers black or darker colors on the Z axis and the saved stl file can then be 3D printed as a relief, flat on one side with the resultant 3D printed image in raised relief format on the other side. The raised relief side of the 3D print has been found to be especially useful in making images from microscopes, telescopes and earth-facing satellites able to be used as tactile graphics for a touch and feel learning experience by blind or visually impaired students[30]. 123D Catch is also useful for making 3D print files from objects that already exist in the real world and only requires knowledge of taking photos with an iPad or iPhone which can then be made into stl files using the Adobe cloud.

Using Quicktime VR files for 3D printing

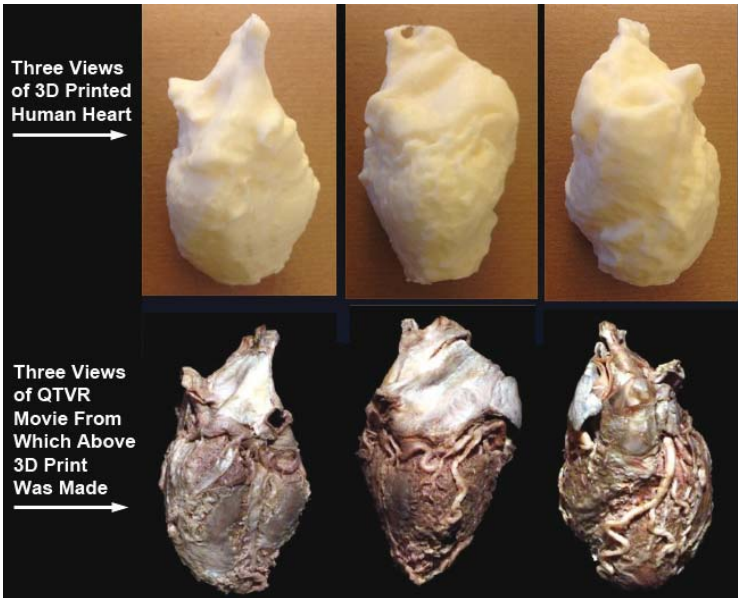
It is also possible to capture images from Quicktime VR movies from 360 degree views and these images can also be sent to the Adobe cloud site using 123D Catch to be made into an stl file for 3D printing. The author has used the heart Quicktime VR movie at the Wright State University Anatomical Resource web site[31] to make a 3D printed heart which demonstrates that any Quicktime VR movie has the potential to also be made into an stl file for 3D printing. See Figure 2 below for example views of the 3D printed heart and QTVR images that correspond to the 3D printed heart views.

Figure 1. Ways to make stl files for 3D printing



Source: Author

Figure 2. Views of 3D printed heart with corresponding QTVR images



Source: QTVR movie images from Wright State University School of Medicine Anatomic Resource (http://www.anatomy.wright.edu/qtvr/index.html), and 3D Print made by author.

[26] The University of Texas at Austin NSF Digital Library, http://www.digimorph.org/, [28.05.2014].
[27] U.S. Department of Health and Human Services – National Institutes of Health, Discover 3D models, http://3dprint.nih.gov/discover, [28.05.2014].
[28] M.A. Kolitsky, *3D Printed Tactile Learning Objects: Proof of Concept*, „Journal of Blindness Innovation and Research" 2014, Vol. 4, No. 1, https://nfb.org/images/nfb/publications/jbir/jbir14/jbir040102.html, [28.05.2014].
[29] Ransen Software, http://www.ransen.com/phototomesh, [28.05.2014].
[30] M.A. Kolitsky, *3D Printed Tactile Learning Objects: Proof of Concept*, op.cit.
[31] QTVR Resource. Library of Anatomical Objects, Wright State University School of Medicine, http://www.anatomy.wright.edu/qtvr/index.html, [28.05.2014].

Examples of ways that 3D prints are being used in education

There are two general ways that 3D printing and 3D prints are being used in education today and the term education is being used in its broadest sense to include not only what happens in the traditional grade school, college and university classroom or lab but also what is happening in museums and libraries. The first approach uses the process of making the 3D print file and then using that file with the 3D printer as a way to prepare students to be exposed to the design process in file production and then to master the hands-on aspect of actually using the 3D printer. The second approach is to use 3D prints as a way to learn something or about something that would not be possible without touching or handling the 3D print itself. The first approach then is more lab-like in that mastering a CAD type program for stl file production is emphasized and hands-on skills are developed in the actual making of the 3D printed object with a 3D printer. The second approach covers how a 3D printed object can be used for learning and is dependent upon having a source for obtaining the 3D printed objects to be included in the learning experience. The first approach has been covered in the previous section and the remainder of this paper will focus on how 3D prints are currently being used or have the potential to be used in education to enrich the learning process.

Engineering

A compilation of projects including case study descriptions in the engineering area involving 3D printing in university courses as well as in grade schools can be seen at the Stratasys web site[32]. Some of those projects include the following: (a) Students at the Architectural and Engineering CAD Department at Austin Community College use 3D printers in collaborative projects where an entire class redesigns a complex system such as a twin valve engine. (b) The Cockrell School of Engineering at the University of Texas at Austin recently introduced a 3D Printer designed as a vending machine for student use at no charge and administrators review the list of student submitted 3D print designs to be sure that nothing is being printed that is illegal. (c) The Budapest University of Technology and Economics used 3D printing to assist in a design challenge to produce an electric fan with enhanced cooling at a lower noise level. (d) Students at Embry-Riddle Aeronautical University replaced the making of wind tunnels from hand-tooled templates with 3D printed wind tunnel models. (e) Maconaquah Middle School in Bunker Hill, Indiana introduced 3D printing into the STEM curriculum as an enrichment program to attract girls into engineering programs that traditionally have been a male dominated field.

Arts

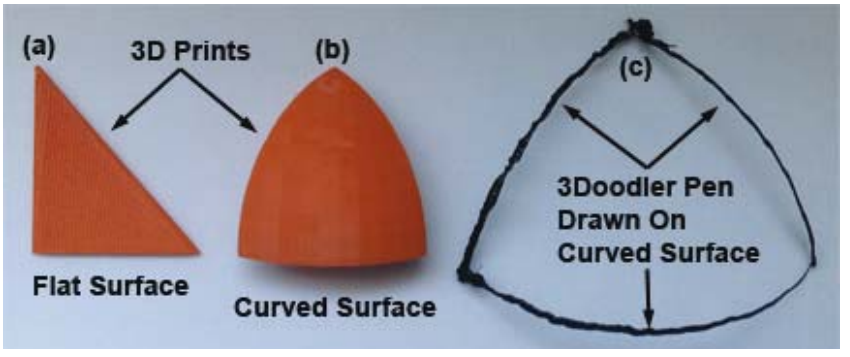
A "Huffington Post" article[33] covers 14 ways that 3D printing is being used to expand how artists make art. Wearable art as well as a replica of Van Gogh's ear have been 3D printed. Images of sculptural self-portraits as well as a 3D printed 1971 Ford Torino by Romanian-born artist, Ioan Florea are also presented. Researchers at The University of Connecticut have been producing rare mouthpieces for 18th Century antique horns from CT scans which expands considerably what can be studied since there are only three original mouthpieces[34]. The author in June, 2014 was asked to present a workshop on 3D printing in a graphics design lab at Middlesex Community College in New Jersey where they installed three MakerBot Replicator 2 3D printers amongst the design lab computers where the students were learning to use Maya to create the CAD stl files for 3D printing. The inclusion of 3D printers in a computer lab provided a tight integration of the digital production process and the art of making that object for the real world.

Mathematics

An excellent pdf titled "3D Printing for Math Professors and Their Students" can be downloaded from Thingiverse[35] to assist in using 3D printing in the mathematics classroom. One lesson of interest to the author is in showing students that not all triangles have internal angles that add up to 180 degrees but rather, that statement is only true in Euclidean geometry where the interior angles are measured in a triangle drawn on a flat surface[36]. The author 3D printed a segment of a hollow hemisphere from a Thingiverse stl file[37] to show that the interior angles of a triangle drawn on the surface of a sphere add up to more than 180 degrees as seen in the following Figure 3. In Figure 3, the 3D printed flat triangle (a) has internal angles that add up to 180 degrees. Triangle (b) in Figure 3 is the 3D printed half section of the hemisphere file

[32] *3D printing means hands-on learning and a brighter future*, http://www.stratasys.com/resources/case-studies/education, [28.05.2014].
[33] K. Brooks, *14 Ways 3D Printing Has Changed The Art World*, „The Huffington Post", 30.06.2014, http://www.huffingtonpost.com/2014/06/30/3d-printing-art_n_5534459.html, [28.05.2014].
[34] S. Taylor, *Uconn's 3D Printing For Antique Musical Instruments*, 3D Printing Industry, 02.08.2014, http://3dprintingindustry.com/2014/08/02/uconns-3d-printing-antique-musical-instruments, [28.05.2014].
[35] E. Aboufadel, S.V. Krawczyk, M. Sherman-Bennett, *3D Printing for Math Professors and Their Students*, Cornell University Library, http://arxiv.org/abs/1308.3420, [28.05.2014].
[36] S. Erickson, G. Felder, *CurvedLand: An Applet to Simulate Curved Space*, http://www.smith.edu/physics/felder/curvedland/tuttriangle.html, [28.05.2014].
[37] MakerBotThingiverse, http://www.thingiverse.com/thing:10714, [28.05.2014].

Figure 3. Comparison of triangle internal angles on flat and curved surfaces



Source: author

downloaded from Thingiverse and the angles add up to 250 degrees. Triangle (c) was hand drawn on a glass sphere using a 3Doodler pen and has internal angles adding up to 270 degrees.

Archaeology/Anthropology

A faculty member at Marshall University who teaches Human Anatomy is using a 3D printer to make smaller objects like teeth larger so that students can study the smaller details now more visible in a larger model[38]. He also predicts that "one-of-a-kind" specimens located elsewhere in the world can be made into 3D prints for study by just getting access to the 3D data file for that object. Anthropology News[39] has reported that 3D printing now provides an option to make artifacts like spear points or fragile waterlogged artifacts from an underwater Mayan research site for showing at conferences to colleagues or for use in the classroom.

Museums and libraries

A library in Lithuania has started a project to make 3D prints of the faces of political figures and celebrities such as Steve Wozniak, the American inventor and co-founder of Apple Inc. who was visiting Lithuania at the time when the project started and also several famous Lithuanian singers and actors. In addition, 3D prints of historical buildings such as the Taj Mahal and Reims Cathedral were also made so that blind or visually impaired people could have the opportunity to touch the 3D printed models of faces and buildings[40]. A sports museum in Finland has begun to make 3D printed copies of sports memorabilia available to visitors so anyone can touch them[41]. The Smithsonian in Washington, D.C. has over 137 million objects but only about 2% of them are on display so a 3D scanning project has begun to make museum objects viewable in 3D form with a number of objects available as stl files for downloading and 3D printing[42]. The DeLaMare Science and Engineering Library at the University of Nevada, Reno was reported to be the first library to offer 3D printing and scanning services to students to incorporate the making of objects into their research and learning[43].

Astronomy

NASA has also been 3D printing images from the Hubble Telescope so that the 3D prints can be made into tactile learning experiences for the blind[44]. Dr. Amelia Ortiz-Gil in Spain developed an astronomical kit for visually impaired students to study the moon's surface using tactile means[45] and is also working on a project called AstroSense which is calling for ideas and sharing of 3D printed astronomy learning projects[46]. The Space Telescope Science Institute on the campus of The Johns Hopkins University campus

[38] *Anthropologist using 3-D printing technology to enhance research and student learning; equipment available to university community*, „We Are Marshall: the Newsletter for Marshall University", http://www.marshall.edu/wamnewsletter/2014/01/15/anthropologist-using-3-d-printing-technology-to-enhance-research-and-student-learning-equipment-available-to-university-community/, [28.05.2014].

[39] H. McKillow, *Abstract: Underwater Maya: 3D Imaging and 3D Printing the Ancient Maya Past*, Archaeological Institute of America, http://www.archaeological.org/lectures/abstracts/13385, [28.05.2014].

[40] S.J. Grunewald, *Steve Wozniak and Lithuanian Celebrities Help the Blind See with 3D Printed Models*, 3D Printing Industry, 01.08.2014, http://3dprintingindustry.com/2014/08/01/steve-wozniak-lithuanian-celebrities-help-blind-see-3d-printed-models, [28.05.2014].

[41] D. Sher, *You Can Look AND You Can Touch, the Magic of 3D Printing*, 3D Printing Industry, 07.04.2014, http://3dprintingindustry.com/2014/04/07/3d-printing-museum-versoteq/, [28.05.2014].

[42] *Smithsonian museum artifacts can now be 3D printed at home*, CBC News, 13.11.2013, http://www.cbc.ca/news/technology/smithsonian-museum-artifacts-can-now-be-3d-printed-at-home-1.2424898, [28.05.2014].

[43] *University of Nevada, Reno library first in nation to offer 3D printing campuswide*, 18.07.2012, http://newsroom.unr.edu/2012/07/18/university-of-nevada-reno-library-first-in-nation-to-offer-3d-printing-campuswide/, [28.05.2014].

[44] *Hubble Images Become Tactile 3-D Experience for the Blind*, NASA, 07.01.2014, http://www.nasa.gov/content/goddard/hubble-images-become-tactile-3-d-experience-for-the-blind/#.U-zt50iLG4U, [28.05.2014].

[45] *Astronomical kit for the visually impaired, Spain*, International Astronomical Union Office of Astronomy for Development, 08.10.2013, http://www.astro4dev.org/blog/category/tf2/visually-impaired/, [28.05.2014].

[46] *Call for ideas: 3D printing astronomy for the visually impaired*, International Astronomical Union Office of Astronomy for Development, 23.04.2014, http://www.astro4dev.org//?s=3D+printer, [28.05.2014].

is using 3D printers to make models of star clusters using different textures with raised lines and bumps to indicate the brightest areas of a telescope image so that blind and visually impaired students can study and learn astronomy[47].

Biochemistry and molecular biology

The recently established NIH 3D Print Exchange[48] already has dozens of 3D print files for many types of protein, carbohydrate and nucleic acid molecules such as DNA and RNA available for download to use in biochemistry or molecular biology courses. A search of Thingiverse with the word "biochemistry" also generated eleven 3D print files for protein domains, a form of RNA helix and a number of protein and vitamin structures in 3D model form. Crystallographers at the University of Houston have developed a way to make 3D prints of crystallographic information so that it is now possible to not only view crystal structures in a virtual sense but also hold the crystal in one's hand[49]. And lastly, a number of uses of 3D printers in chemistry have been reported ranging from making 3D printed lab equipment[50] to actually running experiments with 3D printed reactionware[51] as shown by researchers from the University of Glasgow.

Biology

Another interesting collection of 3D print files for the teaching of human evolution can be found at African Fossils collection[52] that contains many 3D print files of the fossils found by Dr. Louise Leakey. 123D Catch was used to make 3D print files from many of the fossils in the African Fossils collection[53]. An article in the New Zealand Association of Science Educators (NZASE) describes how a high school biology teacher downloads and uses the African Fossil files in the teaching of human evolution[54]. Students and faculty at the University of Notre Dame used data from CT scans to 3D print hard tissues like the skeleton and soft tissue for body organs from anesthetized rats and rabbits[55] which can then be used for research or teaching. The Howard Hughes Medical Institute (HHMI) has produced 3D print files for a number of molecular structures and viruses that can be downloaded as stl files for use in biology education[56]. The HHMI 3D printed models also have learning resources such as short films, lectures and classroom activities linked to them to make them more useful as classroom learning tools. The Milwaukee School of Engineering (MSOE) has established a Center for BioMolecular Modeling that works with science educators to create innovative instructional materials[57] that make the molecular world more understandable for students. Arizona State University (ASU) has supported a student project by Ashleigh Gonzales, a blind student majoring in a STEM degree program in which she has produced 3D tactile boards from 2D images and described her undergraduate research at a conference[58]. ASU has also started a program called 3D-IMAGINE (Image Arrays to Graphically Implement New Education) in which beginning biology and astronomy lab classes will have one section using the 3D tactile boards designed especially for students who are blind or visually impaired[59].

The author has been working with PhotoToMesh[60] to design tactile learning objects to enable blind or visually impaired students as well as kinesthetic learners to study by touch and feel what sighted students see when using a microscope[61]. More recent work by the author has focused on making it possible for audio feedback by using capacitance sensing to detect where on the 3D print a fingertip is touching so that

[47] M. Kramer, *3D-Printed Hubble Telescope Photos Help Blind Touch the Universe (Video)*, SPACE.com, 10.01.2014, http://www.space.com/24233-3d-printed-hubble-photos-blind-aas223.html, [28.05.2014].
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[60] Ransen Software, http://www.ransen.com/phototomesh/, [28.05.2014].
[61] M.A. Kolitsky, *3D Printed Tactile Learning Objects: Proof of Concept*, op.cit.

the tactile learning object can be made to respond by audio, i.e., by speaking or talking, to provide information about the structure or region being touched[62].

Business and economics

There is a growing analysis of how 3D printing is becoming a technology for change in business and economics. Several campus programs in business have established 3D printing labs and have begun to offer courses to train students as well as community business leaders and managers in making decisions based on what 3D printing technologies can offer a business[63]. These courses and programs also focus on entrepreneurship and how to start up a business as well as how 3D printing can be especially useful in making prototypes at an affordable cost[64]. Among such courses, there is even a MOOC (massive open online course) advertised by Deloitte University Press designed for managers and business leaders to better understand how 3D printing can impact their businesses[65]. Topics to be covered in courses studying the impact of 3D printing on business and economics would include study of managerial decision-making, entrepreneurship, statistical modeling, labor practices, copyright law and small business start-ups. An article in "The Economist" has predicted that for manufacturing, 3D printing is likened to the third industrial revolution[66].

Formation of tactile learning objects

3D printed images, 3D printed line graphics and 3D printed Braille as well as methods to add audio feedback can be assembled to form a learning object for use in the real world. Learning objects are defined as stand alone, reusable chunks of learning that can be assembled like Lego blocks for a larger learning experience. Up to now, the majority of learning objects have been designed for the digital world and repositories such as Merlot[67] have over 44,000 learning objects but very few that are classified as learning exercises when a search was done with the terms "blind or visually impaired". It is now possible to begin thinking about a future where larger numbers of learning objects will be available in tactile form and classified as a tactile learning object.

The first step in the process of making 3D printed tactile learning objects begins with making the image 3D prints. A number of projects have begun to do this, such as: the Astrosense project[68] aimed at producing tactile astronomy learning objects and the Space Telescope Science Institute that is designing 3D printed textured Hubble images[69]. The 3D-IMAGINE program at Arizona State University is making 3D printed tactile boards for study in astronomy and biology labs[70] and it was reported recently that researchers at the University of Colorado Boulder are creating 3D printed children's books designed to introduce blind children to reading[71]. A proof of concept approach was confirmed by the author in a publication in April, 2014 where examples of 3D prints of astronomy, cell biology, histology and anatomy images were shown along with an example of 3D printed tactile learning object comprised of a 3D print image of a cell in telophase stage of mitosis, a 3D printed line graphic, inclusion of both structure identification in Braille and also available as audio feedback using the LiveScribe pen[72]. All of these beginning efforts speak to the need for a more widespread future collaboration which will be required to make the 3D prints for the many other image intensive courses in a typical curricular offering.

[62] M. Kolitsky, *3D Printed Talking Tactile Learning Objects will make Learning by the Blind More Compliant*, Proposal No. 1989, 17th Annual Accessing Higher Ground Accessible Media, Web and Technology Conference, 17–21.11.2014, Westminster, CO, http://accessinghigherground.org/wp/show1prop4grid2014.php?vpropid=1989&vday=Thursday&vdis=grid, [20.09.2014].

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Intellectual property rights issues

The widespread availability of 3D printing technologies not only broadens what opportunities teachers and students have for making things for learning but also raises the risk of making things teachers and students do not own or have permission to make. For example, it was reported by Carson[73] that figurines of South Park characters or Star Wars Stormtroopers can be found by searching on Shapeways or Thingiverse, both popular sites for finding downloadable files for 3D printing. But, because Shapeways and Thingiverse have a posted policy that they will take down any files a copyright holder asks to be taken down, the Digital Millennium Copyright Act protects Shapeways and Thingiverse under what is called a safe harbor defense. Carson also highlighted a creative licensing agreement by Shapeways[74] and Hasbro[75] to permit select 3D artists to design 3D print files of "My Little Pony" figurines that can be downloaded for a fee. Now the copyright holder (Hasbro), the 3D designer and Shapeways will be able to make money in this arrangement. This type of innovative licensing agreement may portend how future sharing of copyrighted 3D print files will occur.

Copyright issues are always balanced by fair use and applies especially to how instructors can use copyrighted works for teaching and learning[76]. 3D printing technologies have disrupted traditional thinking about copyright, fair use and derivative works. For example, how much of a copyrighted image is changed when a 3D print is made of that image and can it now be defined as a derivative work? If a copyrighted 3D print file is used to make a single copy for educational use, is that permissible and is that different from making multiple copies of the same object? Who in the educational setting should oversee institutional 3D printers to ensure that copyright infringement does not occur? It does appear that the legal system will be kept busy determining how copyrighted works can be used in a fair manner in the educational setting.

Environmental concerns about 3D printing

There have been a number of concerns raised about the expected widespread usage of 3D printers and several apply directly to their use in educational or home settings[77]. 3D printers were reported to utilize more energy to melt plastic with heat or lasers than making the same object using injection molding. More energy means more electricity and concerns about how electricity is generated.

There may also be a health risk connected to the use of 3D printers in that it has been shown that 3D printers emit nanosized particles during the printing process[78]. Desktop 3D printers made for the consumer market utilize either PLA or ABS plastic filament that is extruded onto a surface to build an object. PLA filament was reported to emit 20 billion ultrafine particles per minute and ABS filament produced 200 billion particles per minute. These particles can be breathed into lungs and may be a concern for people with asthma.

Lastly, there has been a growing trend to reduce our dependence on plastics and replace plastics with recyclable materials. PLA is considered as being "green" because it is made from polylactic acid and is also biodegradable. But, ABS filament is commonly used with consumer grade 3D printers and is not biodegradable and would last a long time in landfills.

Prognostication is risky business

Despite all the exciting and novel ways that 3D printing is currently changing the way we think about what we can do in the classroom and laboratory experience, it is still very early for predicting what the overall impact will be of widespread integration of 3D printing across the curriculum. And we know that prognostication is risky business. For example, a few years ago, I came across an old 1932 issue of Readers Digest that republished an article by Lewis Mumford[79] titled "In Our Stars, Fifty Years from Now". In the article, the automobile industry saw a future in which cars would be painted with special paint containing radium so that cars would glow in the dark and be more easily seen at night and highways would also be impregnated with radium to glow at night alleviating the need for overhead lighting. Those predicting this use of radium obviously had no knowledge at that time of the ionizing effect of radiation on the human body. So, keeping in mind that prognostication is risky business, what has been discussed in this paper is one prediction for how 3D printing will impact learning and also form the foundation for what we think we can do in our classrooms and laboratories in the future. Only time will tell if we have any radium coated cars in our future.

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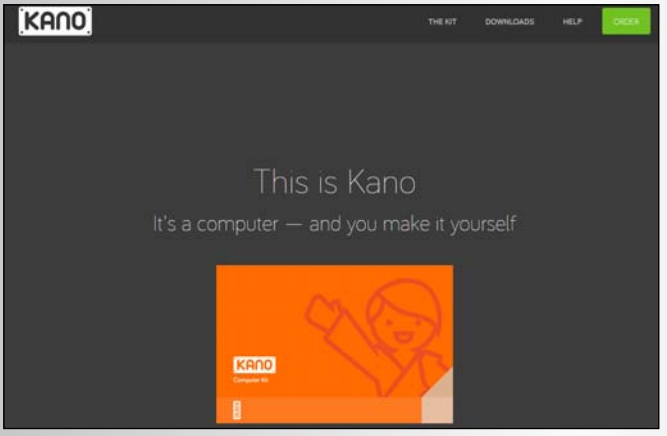
Mike Kolitsky received his Ph.D. in cell physiology from Temple University in Philadelphia, PA and is now retired but teaching online courses in Histology as well as Anatomy and Physiology I and II lecture and lab for The University of Texas at El Paso (UTEP). He was a tenured professor of Biology at UTEP and also was appointed Associate Vice President for Instructional Technology to oversee the technology design and faculty training for a new Undergraduate Learning Center. He was the Principle Investigator for a 2.5 million dollar NASA grant to establish an instructional support and training center at UTEP for University and regional K-12 instructors. He also received a University of Texas Chancellor's Distinguished Teaching Award at UTEP and earlier was awarded a Distinguished Natural Sciences Curriculum Innovation award for his Embryology videodisc and HyperEmbryo courseware from EDUCOM. After leaving UTEP, he was appointed a founding board member for NJEDge.Net, the higher education network for New Jersey. He was a consultant for the Rutgers University Library FIPSE grant to establish the New Jersey Digital Highway and also assisted in the production of several shared content objects with The University of Wisconsin–Madison Academic ADL Co-Lab FIPSE-sponsored effort to support effective online teaching. The Author is currently interested in 3D printing and how it is changing the way teachers teach and students learn. He is currently exploring how to provide audio feedback for 3D printed tactile learning objects so that blind or visually impaired students can study by touch and feel what sighted students see when using a microscope.

Polecamy



Kano

Nauka programowania w prosty i przystępny sposób? Na taki pomysł wpadli twórcy Kano – komputera, który można samodzielnie zbudować w kilka minut i samodzielnie zaprogramować. Projekt ten ma przede wszystkim walory edukacyjne – jego głównym celem jest zachęcenie użytkowników do nauki podstaw programowania. Zestaw Kano Kit zawiera procesor Raspberry Pi model B, kartę pamięci SD, na której znajdziemy KANO OS, czyli zmodyfikowanego Debiana wraz z oprogramowaniem edukacyjnym, głośnik, klawiaturę, obudowę, okablowanie konieczne do używania komputera, zasilacz, moduł Wi-Fi i dodatki pozwalające użytkownikowi spersonalizować wygląd swojego minikomputera. Do zestawu dołączono także prostą instrukcję, a bardziej dociekliwi użytkownicy znajdą dodatkowe informacje na blogu.
Więcej informacji można znaleźć na stronie: **http://www.kano.me**