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As a technology educator for more than 25 years, it has been a distinct privilege to witness the continuing fascination and high engagement wrought by successive waves of new technologies upon student learning in my classroom. Ranging from writing their first webpages in HTML and uploading them to the Internet, to rendering their first animations, producing their first videos, and compiling their first sets of programming code, students continually approach technology learning with an enthusiasm that has been a source of energy and delight throughout my career.

However, even given students' great enthusiasm for a variety of technologies, I would be hard pressed to offer a technology that has drawn such complete fascination—and, likewise, built such confidence in their ability to take rapid ownership of it—than the arrival of 3D printing. Born in industry during the 1980s and continually improved to meet the new demands created by customized online ordering, its recent introduction into the consumer market has ignited the home-based manufacturing world in much the same way that desktop publishing transformed the home-based printing industry 30 years ago.

Thankfully, the entry of this amazing technology into the consumer market, made possible by breakthroughs in machine size and material costs, has likewise enabled schools around the world to join this new manufacturing movement. As a result, students now have the unprecedented ability to conceive, design, improve and print a low-cost, high-quality, purpose-made object that is in their hands within hours. As my 3D implementation team colleagues and I discovered, this begins a beautifully iterative process that soon leads to bigger ideas and more complex designs—as well as to more socially conscious manufacturing goals.

This article describes how we, a team of educators in a Catholic secondary school, integrated 3D printing into our learning environment. We present our methodology for incorporating complex design projects that embody the highest ideals of service for others in the following sequence. First, we describe our initial year of implementation, including best practices de-

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rived from our experiences. Next, we describe efforts in the second year to expand our program goals to include designing and printing for others in need. These descriptions are paired with a discussion of outcomes and lessons learned through our 3D printing endeavors so far. Lastly, and perhaps most importantly, we make a series of recommendations for educators who not only wish to introduce a 3D printer into their faith-based curriculum, but who also desire to see their students develop the skills and vision needed to become what Pope Francis calls "…the protagonists (and) artisans of the future" (Assaf, 2015, n.p.).

Context

Christ The King Jr./Sr. High School is located in Leduc, Alberta, Canada, and serves approximately 540 rural and urban students. We are proud of our consistently high academic standing, which often exceeds the Provincial average for core subjects. We began the integration of a 3D printer into our Career and Technology Studies (CTS) program at the grade 10-12 level, after three years of developing the relevant basic skills (hardware diagnostics, electronic publishing, and graphic design, in particular) at the grade 7-9 level. Our CTS Program uses several 1-credit modules in Computer Science, Communications Technology, Design Studies, Information Processing, and Networking to create engaging, personally-relevant career-path courses for each student in the program. Thus, for students who wish to pursue 3D printing, their CTS course can be individualized each year to include as many 3D printing modules as possible.

Year 1

In the overall context of our implementation plan, Year 1 involved learning to use the technology through a variety of exciting teacher and student-led experiments and projects. These activities consisted of gaining familiarity with basic printer operations (loading and changing printer filament), leveling the print deck (a very precise skill), establishing our longest printing record (a 14-hour overnight print), creating our first two-color design, and learning how to print a double-sided item (text on one side with an image on the other). We developed advanced daily and monthly maintenance procedures in order to avoid filament clogs inside the printhead (thereby reducing the chance of the printer being away for lengthy repairs), and also experienced the excitement of initial curriculum integration as the printer began to be used by students to assist their work in subjects other than CTS. From this wonderful year of experimentation and mutual teacher/student learning, our derived "best lessons learned" are summarized in Table 1:

Table 1

First Year Implementation (Derived Best Practices)

Best Practice	Explanation/Rationale
Level the build plate every two weeks.	This action has proven to be sufficient to ensure two weeks of accurate prints.
Don't lose the level card.	This business card sized piece of paper will allow you to calibrate the build plate to a few hundredths of a millimeter efficiency. We keep it in the build case that came with our MakerBot Replicator 2.
Put new painter's tape on the build plate every two weeks. A few sheets are supplied upon purchase. Additional tape can be purchased at a hardware store.	Our first few prints were directly on the acrylic build plate, and were very difficult to remove. Once we began printing on the painter's tape, removing said designs became much easier.
Understand the proper use of rafts, and especially supports, to avoid waste and valuable print time.	While designing in Tinkercad, there is no gravity, and objects can be designed and rotated with ease. However, once on the build plate, flat structures benefit from adding a raft (a clickable option in the software) that enables easier removal once done. Extended structures (like outstretched arms and horizontal wings) definitely require supports, which are light plastic scaffolds that enable these objects to be printed with high detail in mid-air.
Keep a set of fine tweezers and a standard nail file nearby (we have ours in the same small box as the level card).	To assist with removal of designs, fine tweezers enable us to easily pry the raft off of the tape, after which the object can be easily removed from the raft by hand. The file allows any small 'filaments tags' to be quickly and smoothly removed.
Return filament spools to their bags.	This action helps keep dust and grit from attaching to the filament, which could alter the print color and quality of objects.
Create an Exemplar wall.	A wall in my classroom has examples of Tinkercad lessons, a display of selected students projects, and the initial results of my team's research interests (which currently center around how to create multi-color objects with a one-color printer).

In summary, we began with a new learning technology, had staff and students respond with great enthusiasm, continuously experimented, and developed a working body of best practices. We were pleased with the growth in our students' skills as well. After a year of working with the 3D printer, our students were able to complete 10 introductory tutorials on Tinkercad.com, find and modify printing templates from the online design community Thingiverse.com, and create their first original design within their Tinkercad.com design area. Perhaps most importantly, we established a community of student-leaders who were eager to work with it next year. Overall, our first year was a success!

Year 2

Following our first successful year of integrating a 3D printer into our CTS program, we began a systematic search for projects that would simultaneously help our students improve their design skills while also incorporating community service. The initial reason we decided to look for ways to incorporate service into our 3D printing program was based upon how quickly our students developed their 3D printing design skills. We saw this happening not only in class, but also at home! Since the Tinkercad.com design space is web-based (each student creates a free user account that is accessible by any computer that has Chrome), we were distinctly pleased to see that several students soon regarded working on their design projects as an ongoing continuum (i.e. wherever they were didn't matter; having access to their design space to focus on completing their design, did). In other words, we were experiencing students happily working through each phase of our instruction, continuing it at home (which is technically homework, is it not?) while not seeing any difference between the two, which led to us receiving several high-quality completed assignments from still-engaged students who desired to do more. It was very rewarding to see the joy of work and accomplishment they derived from this new educational experience!

At this time, we began to realize that our students needed more challenging assignments to further develop their design skills. We also wanted to ensure—as much as possible—that any new projects were infused with a distinct social purpose. As a result, several projects were researched and evaluated, chief among them being the CityX Project (www.cityxproject.com). It became our first choice, since it involved students working as a group to support a fledgling colony on Mars. By developing designs for needed equipment that could then be transmitted to the colony's 3D printer, the project's unique six-step iterative and collaborative design process fostered the initial social awareness and support we were looking for, albeit at a simulated distance.[1] However, as our research continued, an amazing opportunity presented itself: an opportunity that not only combined the ongoing improvement of our 3D program and our students' design skills, but one that also gave them the ability to respond to a clear social need and to see the positive results of their actions.

Thus, the e-NABLE campaign (http://enablingthefuture.org/), initiated by Dr. Jon Schull at the Rochester Institute of Technology and coordinated by a worldwide volunteer community, became (out of 10 projects that we developed during the course of Year 2) our primary choice to fulfill these amazing opportunities. In brief, this campaign is powered by thousands of tireless volunteers around the world, each of whom seeks to use

> …their 3D printers to create free 3D printed hands and arms for those in need of an upper limb assistive device. They are people who have put aside their political, religious, cultural and personal differences… to come together and collaborate on ways to (better design and print) hands and arms for those who…who have lost them due to war, disease or natural disaster. (http://enablingthefuture.org/about/)

We immediately realized that we could contribute to this world-wide social need. We had a 3D printer, a core of students with the appropriate skill-sets to print and assemble them, and the time to incorporate this initiative into our curriculum via the aforementioned 1-credit modules. Truly, we felt the call to respond and help make a difference.

Therefore, we decided to have our school, and by extension our CTS students (where and when possible in their respective CTS courses), become part of this worldwide social service campaign. In order to achieve this, we decided that our primary material requirements (several spools of PLA filament and a dedicated e-NABLE 3D printer) would be provided by a series of fundraising activities to support this initiative. These activities would create unique opportunities to engage in weekly and/or monthly social awareness events, while steadily working towards our ultimate goal of actually being

1 It is worth noting that the relevance of the CityX Project as our first choice was heightened due to the incredible events occurring aboard the International Space Station at the same time (Dec., 2014). In brief, the first 3D object printed in space—based on a template designed on the ground and transmitted to the 3D printer aboard the ISS, independent of astronaut design input—was accomplished, thus proving a powerful, real-time positive reinforcement to the long-term technical and social relevance of this particular project.

able to provide a 3D printed grip-capable hand for a child in need (at no cost to the child whatsoever). Now, just two things remained. First, to find a reliable supplier of wire, screws, and Velcro straps (so we would not have to source from multiple suppliers) in order to efficiently assemble our sample hand. Second, to send our sample hand away for quality approval. Happily, both of these objectives were achieved.

3D Universe (www.3duniverse.org/) was ultimately chosen as our supplier. With the use of its low-cost, all-parts-in-one kit that quickly arrived, we were able to print, assemble our first sample hand, and mail it to a specialized e-NABLE volunteer (located in Opelika, AL, USA) for print-quality verification. Altogether, our first print and assembly process involved creating 26 3D parts during a 10-hour print, followed by a careful 8-hour assembly process, for a cost of approximately $50 CAN.

When we received the good news re our quality approval (which was a very good day indeed!), we knew our students were now truly ready for their next big steps into a wonderful new world of social awareness empowered by service learning. Those steps would begin by being linked up with a member child, printing and assembling their custom hand according to their unique specifications (measurements provided by e-NABLE), mailing it to them, and then hopefully contacting them—whether in person or via social media—in order to see the delivery, fitting on, and fantastic first use of this most wonderful and rewarding service learning initiative.

At this stage of our implementation, as Year 2 comes to a conclusion, our goals are threefold. First, to continue setting into motion the ongoing machinery (after applying for, and having received, free membership in the e-NABLE community) that will allow us to effectively integrate the e-NABLE project into our existing courses. In particular, our students can experience some complications in participating in our high school (grades 10-12) 3D printing modules, since they are dependent on the completion of a provincially mandated sequence of prerequisite modules (which are important and valuable since they ensure each student will have a basic skill set in place before they begin their adventures in 3D printing). Adding to this is the reality that students have the choice of completing their prerequisites in either of the three grades. As a result, in Year 2 much work went into (and will continue to go into) developing and improving our sequence of 3D printing modules that will enable students—at any grade level—to complete the necessary prerequisites and then have an extended range of 3D modules to enjoy, whether for one year or all three of their high school careers.

Our second goal involves the continuing development of our students' short-term social service responsibilities (participating in weekly and/or monthly fundraising activities to ensure continued printing materials availability). This will help us to begin fostering our third goal—the raising of their long-term social awareness, i.e. the empowering realization that once this particular weekly or monthly service project is done it's not 'over for the year'. Instead, it is but one part in the ongoing sequence of our over-arching goal: to hopefully provide at least one limb for a child per school semester. And, God-willing, as this project becomes an established and ongoing part of who we are, we hope to be able to print even more.

Recommendations for Schools Interested in e-NABLE

We can certainly recommend getting the quickest start possible since there are many ways that students can promote their school's participation in the e-NABLE community, even if printing a 3D hand is not something they wish to do. Such activities can include writing and photographing assembly instructions, creating how-to videos (to help those both printing and building the object, as well as for those who will put their new hand on and excitedly use it for the first time), and updating a school Google Map which shows the locations of the children they've been able to provide a hand for. As is evident, the range of valuable digital skills that are enhanced by participating in the e-NABLE project in just the above examples include writing, graphic design, electronic publishing, video pre-production, production, post-production, and website design and maintenance. Factor in the ongoing development of both short and long-term social skills, and the e-NABLE project truly become a gift that keeps on giving—for all involved.

In regards to staff development, the earlier a staff's 3D printer team can join the e-NABLE community, become familiar with the many ways they can contribute, and begin researching and designing a range of engaging activities for the students, the better! Come September, the overall program has a much better chance of hitting the ground rolling and engaging students' enthusiasm, along with other interested staff members as well.

In addition to the above recommendations, we would definitely like to stress the importance of engaging the awareness and close support of your district's IT department. When a 3D printer malfunctions, it can be days or weeks until it's functional again, depending on the problem, availability of said technicians, and the time involved in delivering a new part. Also, there are a number of 'quick fixes' related to clearing jammed filament that our techs have been able to demonstrate, and those have proven invaluable in restoring our printer to functionality in a matter of minutes (versus weeks) on more than one occasion. As well, their research and awareness of ongoing trends in this rapidly changing field, especially in relation to improved machine models and changing filament costs, continues to save my team and I a great deal of time and energy—which we are more than happy to devote to the ongoing implementation and improvement of our 3D printing program. Thus, by taking care of your techs, they will certainly be able to take care of you and your 3D printer; which is a most eminently agreeable relationship!

In conclusion, one of the most important things we would like to highlight is the importance of having your students involved in all aspects of working with your classroom's 3D printer. From levelling the build plate and changing the filament, to understanding the different cost, print times, and output quality associated with 0.1 mm versus 0.3 mm resolutions, we found that the aforementioned student engagement is heightened even further when they are able to enjoy ownership as well. Furthermore, we've observed something occurring—as a result of this heightened engagement—that gives us even more hope for the continued success of our 3D printing program and our integration of social service projects within it.

What we've observed can best be described as 'social manufacturing,' which is a term we've developed to encompasses two wonderful dynamics. The first involves the awareness and desire to serve others (as we've been called to do) with faith-inspired and service-oriented creativity. The second includes a unique in-class social dynamic that reflects an inspired cycle of learning, sharing, and continuation of the learning cycle, especially in regards to the collaborative nature that these social-awareness projects engender as they proceed from concept to completion.

The basis of this 'social-learning' dynamic has been observed elsewhere, and is effectively described by Katya Anderson, CEO of Cricket Media. Essentially, when a student "…starts to achieve mastery, they want to show and teach others what they have learned…(and)…when this is done within a community, this starts a feedback loop where learning, mastery, sharing and collective growth happen."[2] Happily, the phenomena of students using technology in such an effective learning cycle is not an entirely new occurrence in my lab. However, when combined with service learning, it takes on a new and most unique vibrancy that is a blessing to behold.

2 https://www.linkedin.com/pulse/big-idea-2016-meet-new-kings-content-katya-andresen

Therefore, if you would like to integrate a 3D printer into your program of studies, whether to support a range of technical modules or a certain aspect of your particular grade level, engage your tech department, like-minded colleagues, and definitely your students. Provide them the opportunity to become a part of something much bigger than themselves—the lifelong gift of truly being able to give for others—and they, along with the ones they help, will be transformed forever.

References

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